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OPERATIONAL EXPERIENCES OF TURBINE-POWERED COMMERCIAL TRANSPORT AIRPLANES

By Staff of Langley Airworthiness Branch

Langley Research Center
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PREFACE

The NASA VGH program on turbine-powered commercial transports was initiated a number of years ago with the introduction of these aircraft in service. Recently a considerable amount of data was evaluated for three types of turbojet transports and three types of turboprop transports. The areas covered included: (1) landing-contact conditions, (2) operating airspeeds, (3) oscillatory aircraft motions, (4) maneuver and gust accelerations, and (5) unusual flight events. A summary of these data is presented in this report with each operational area being covered by a separate paper. In the paper on landing-contact conditions, data obtained from camera measurements on various classes of transports are used to complement the VGH data.

I. AIMS AND SCOPE OF THE NASA VGH PROGRAM ON TURBINE-POWERED TRANSPORTS

By Joseph W. Jewel, Jr.

SUMMARY

The aims and scope of the NASA VGH program on turbine-powered aircraft in commercial operations are discussed. A brief description of the VGH recorder and its accuracies is given.

AIMS OF VGH PROGRAM

Prior to the introduction of turbine-powered aircraft in commercial service, a number of concepts regarding the operating speeds and speed margins relative to the design structural speeds were evolved by industry and government agencies for application to this class of airplane. Inasmuch as no experience was available from routine operations at the time, there was some question concerning the applicability of these new concepts. Consequently, the NASA initiated a program to obtain data on the airspeed operating practices of turbine-powered commercial transport airplanes during routine operations. NASA VGH recorders (ref. 1) were used in this program to obtain time-history records of airspeed, acceleration, and altitude. Some of the initial results from this program are reported in references 2 and 3.

In addition to providing data on the airspeed operating practices, the VGH records also constitute a valuable source of information pertaining to a number of other aspects of turbine-powered transport operations. Some of this information pertaining to random deviations from cruise altitudes is reported in reference 4. Additional information relating to landing-contact conditions, gust and maneuver loads, speed exceedances, and unusual flight situations has been evaluated for a number of turbine transports and is presented in the following papers.

SCOPE OF VGH PROGRAM

The VGH program encompassses the collection of data from several types of turboprop and turbojet transports operating on a number of domestic and transoceanic routes. These routes were selected to provide a representative sampling of airline operations in the United States. In addition, data are being collected from one foreign airline engaged in transoceanic operations.

The VGH data currently available have been collected on three types of turboprop and three types of turbojet airplanes. Some of the basic characteristics of these airplanes are listed in table I. The airplanes designated I, II, and III are turbojets, whereas those designated IV, V, and VI are turboprops. Different series of a given type of airplane have been noted by the designations, A, B, C, and D.

The sizes of the VGH data samples presently available are given in table II in terms of the number of airlines represented, the number of airplanes instrumented, and the number of flight hours recorded by each of the instrumented aircraft. As a matter of interest, it may be mentioned that the total available VGH data sample represents about three-fourths of 1 percent of the total turbine-fleet time.

NASA VGH RECORDER

The NASA VGH recorder (ref. 1) consists of two primary units. The first unit is the recorder base which houses an airspeed diaphragm, a static-pressure diaphragm, and a galvanometer element. The second unit is an accelerometer box which contains a cantilever beam equipped with strain gages to sense normal accelerations. This box is mounted as near as possible, usually within 5 feet, to the aircraft center of gravity. The recorder base is generally mounted in a convenient location, such as on one of the radio racks, to facilitate the installation and removal of film drums. Electric motors in the drum drive the film at a rate of about one-half inch per minute so that a time history of the indicated airspeeds, the pressure altitude, and the normal accelerations of the instrumented airplane is recorded.

ACCURACY

The accuracy of the data presented herein depends on three factors: (1) inherent instrument errors, (2) installation errors, and (3) reading errors.

Inherent Instrument Errors

The inherent instrument errors and a general discussion of installation errors are given in reference 1. As discussed therein, the airspeed and altimeter elements in the VGH recorder are subject to a sensitivity change due to temperature of 1 percent (in pressure) for a temperature change of 50° F. On the basis of estimates of environmental temperature extremes to which the recorders were exposed, the maximum inherent errors in airspeed and altitude are estimated to be within the following:

Turbojet installations:	
Indicated airspeed in cruise, knots	± 1.5
Indicated airspeed at take-off and at landing, knots	± 0.7
Indicated pressure altitude in cruise, ft	± 225
Turboprop installations:	
Indicated airspeed in cruise, knots	± 0.2
Indicated airspeed at take-off and at landing, knots	± 0.1
Indicated pressure altitude in cruise, ft	± 50

The inherent dynamic response characteristics of the acceleration sensor and galvanometer element are flat to within 1 percent over the frequency range of 0 to 4.5 cycles per second, which covers the range pertinent to the present data.

Installation Errors

The recorder installations used to obtain the data met the basic installation requirements given in reference 1. In general, the acceleration transmitters were installed quite close to the center of gravity of the airplane, and the airspeed and altitude-pressure lines were connected to the copilots' system or to an equivalent system having balanced static ports. Static-source position errors are present in some of the data to about the same extent as they are present in, say, the copilots' instruments. The errors are not of major importance in the presentation of the results, however, inasmuch as the data are generally compared with airplane handbook or manual values of indicated airspeed and altitude which also include the effects of static-source position errors. (In determining the airspeeds at landing, the indicated values of airspeed were corrected for static-pressure error as is discussed in a subsequent section.)

Reading Errors

Most of the acceleration, airspeed, and altitude data were read with the aid of manually operated readout equipment. For the accelerometer trace the maximum reading error was estimated to be ±0.03g. The maximum reading error of the altitude trace was estimated to vary from about ±50 feet at 5,000 feet to ±200 feet at 40,000 feet. The maximum reading error of the airspeed trace varied from about ±5 knots at 100 knots to ±0.5 knot at 350 knots.

Maximum Overall Error

Based on the foregoing considerations of inherent instrument errors, installation errors, and reading errors, the estimated maximum total errors in the measurements are:

Acceleration, g units	±0.05
Altitude, ft:	
At 5,000 feet	±75
At 40,000 feet	±500
Airspeed, knots:	
At 100 knots	±6
At 350 knots	±2

The derived results in the subsequent papers are averages of a number of observations, so that the random errors would be expected largely to disappear. The overall errors listed in the preceding table are relatively small and would have only a minor effect on most of the derived results. In the case of the cumulative-frequency distributions of accelerations and gust velocities (papers V and VI), however, the errors in the evaluation may lead to errors as large as ±20 percent in the estimated number of accelerations or gusts greater than a given value. (See ref. 2.)

The indicated airspeeds at landing contact were read, by using special equipment, to an accuracy of ±0.5 knot at 150 knots. In determining the calibrated airspeed at landing (paper II) a correction for static-pressure error of the static-pressure source was applied to the indicated impact pressure. This static-pressure error was determined from the difference in indicated pressure altitude at the time of landing contact and at the time the airplane stopped subsequent to the landing. On the basis of: (1) the reading accuracy of this pressure difference, (2) the reading accuracy of indicated airspeed, (3) the temperature effect on the airspeed diaphragm, (4) the increase in height of the altimeter above the runway at landing contact due to rotation of the airplane, and (5) the assumption that, due to runway slope, the point of landing contact may be as much as 30 feet higher or lower than the point at which the airplane is at rest, the error in calibrated airspeed at landing contact is estimated to be within ±3.0 knots (maximum probable error) at 150 knots. If the accuracy in calibrated airspeed and the fact that the ambient temperature may be as much as 40° or more from standard are considered, the true airspeed at landing contact would be within ±7 knots (maximum probable error) at 150 knots if the calibrated airspeed is taken to be the true airspeed.

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TABLE I.- AIRPLANE CHARACTERISTICS

Airplane designation		Propulsion	Maximum gross weight, lb	Wing area, sq ft	Wing span, ft
Type	Series				
I	A C,D[a]	Turbojet Turbojet	245,000 311,000	2,433 2,892	130.8 142.4
II	A B C	Turbojet Turbojet Turbojet	273,000 276,000 310,000	2,771 2,771 2,771	142.4 142.4 142.4
III	A	Turbojet	189,500	2,000	120.0
IV	A	Turboprop	113,000	1,300	99.0
V	A	Turboprop	35,700	754	95.2
VI	A	Turboprop	63,000	963	93.7

[a]Series C and D differ primarily in having different makes of engines.

TABLE II.- SIZE OF VGH DATA SAMPLES

Airplane designation	Number of airlines	Number of airplanes	Flight hours
I-A	2	2	2,511
I-C	2	2	2,164
I-D	1	2	513
II-A	1	1	135
II-B	2	3	1,515
II-C	2	3	1,687
III-A	1	2	800
IV-A	3	6	5,626
V-A	1	2	1,899
VI-A	1	1	1,838
Total	---	24	18,688

II. LANDING-CONTACT CONDITIONS FOR TURBINE-POWERED AIRCRAFT

By Joseph W. Jewel, Jr., and Joseph W. Stickle

SUMMARY

Landing-contact conditions recently obtained on turbine-powered transports in commercial operations from special camera measurements and VGH recorder measurements are reviewed. An analysis is made of various factors affecting vertical velocity, impact acceleration, and touchdown speeds. A correlation of vertical velocities of piston-engine, turboprop, and turbojet transports is presented to show how various parameters (aircraft weight, wing loading, distance of pilot forward of main landing gear, mean touchdown speed, and effectiveness of elevator in changing the flight-path angle) vary with vertical velocity at impact.

INTRODUCTION

Information on landing-contact conditions of turbine-powered transports in routine commercial operations has recently become available from two sources: camera measurements and VGH records. The investigations reported in references 1 and 2 involved the use of a special camera in photographing landings of one type of turboprop and two types of turbojet transports. The contact conditions determined from the photographs included vertical velocity, forward speed, rolling velocity, bank angle, and the distance of the point of touchdown from the runway threshold. In addition to such information, VGH records have recently been evaluated for these and three other types of turbine-powered aircraft for forward speed and center-of-gravity vertical acceleration at landing impact and center-of-gravity vertical acceleration immediately prior to impact. The purpose of this report is severalfold:

(1) To review briefly the results of camera measurements of vertical velocities and forward speeds at landing impact for turbojet and piston-engine transports

(2) To show the effect on vertical velocities of such factors as operator, aircraft physical characteristics, and flight-path-control parameters

(3) To present data on landing-impact accelerations obtained from VGH records

(4) To show the effect on landing-impact accelerations of other landing-contact conditions

SYMBOLS

a_n	increment of normal acceleration, g units
$\bar{c}$	mean aerodynamic chord, ft
C_L	lift coefficient
C_{L_α}	lift-curve slope, per deg
C_m	pitching-moment coefficient (c.g. at 25 percent M.A.C.)
$C_{m_{\delta_e}} = \frac{\partial C_m}{\partial \delta_e}$	per deg (c.g. at 25 percent M.A.C.)
g	acceleration due to gravity, 32.2 ft/sec^2
h	height of pilot's eye level above ground with airplane in taxi attitude, ft
k_Y	radius of gyration about Y-axis, ft
l	horizontal distance from pilot to main landing gear, ft
m	mass of airplane, slugs
q	dynamic pressure, lb/sq ft
S	wing area, sq ft
V	velocity, ft/sec
V_s	stall velocity, ft/sec
V_v	vertical velocity, ft/sec
$\bar{V}_v$	mean vertical velocity, ft/sec
W_L	landing gross weight, lb
α	angle of attack, deg
δ_e	elevator deflection, deg

μ airplane relative-density coefficient, $\frac{m}{\rho S\bar{c}}$

ρ density of air, slugs/cu ft

CAMERA DATA

Vertical Velocities at Impact

As a means of reviewing the vertical-velocity experience of piston-engine transports, the probability distributions of vertical velocity at landing impact for individual types of piston-engine airplanes are shown in figure 1. These data are for nongusty, clear-weather, daytime conditions and were obtained from investigations conducted at the Washington National Airport (ref. 3) and at the San Francisco International and Denver Airports (ref. 4). The upper and lower limits of the distributions in figure 1 are used for subsequent comparisons of the vertical-velocity experiences of piston- and turbine-powered transports. (In refs. 1 and 2 the vertical-velocity experience of piston-engine transports used for comparison with the turbine transports was based on combined data obtained during each investigation of the piston-engine transports. Consequently, the spread in the results of the piston-engine transports used in the two references is considerably smaller than the spread between the individual distributions given in fig. 1.)

The vertical velocities at landing impact for one type of turboprop and two types of turbojet transports are shown in figure 2 as the probability of equaling or exceeding a given value of vertical velocity. For comparison, the crosshatched area shows the range of results for piston-engine transports. The results for the turbine-powered transports were taken from references 1 and 2 and those for the piston-engine transports, from figure 1. The data for both types of airplanes are for nongusty, clear-weather, daytime conditions.

The data of figure 2 (as pointed out in ref. 2) show that the vertical velocities at landing impact for the two types of turbojet transports are appreciably higher than those for the turboprop and the piston-engine transports. These higher vertical velocities have caused considerable concern in that both the piston-engine and turbine transports are designed to the same minimum-limit vertical velocity of 10 ft/sec in accordance with Civil Air Regulations. (See ref. 5.) The higher vertical velocities for the turbojet airplanes, therefore, tend to reduce the design margins relative to those for past operations with piston-engine airplanes. In addition, the higher vertical velocities for the newer airplanes are of concern regarding their possible implications for future aircraft. Unless the reason for this increase is understood there is a possibility that future transport aircraft, the supersonic transport for example, may experience even higher vertical velocities in landing. In this connection, questions have been raised regarding the effect of various flight and aircraft parameters on the vertical velocities. An analysis of the effect of a number of such parameters has been made and is discussed in the following section.

Effect of Various Factors on Vertical Velocities of Turbine-Powered Transports

The data obtained in the investigations reported in references 1 and 2 were essentially for three operators of type I turbojet transports (designated turbojet A, in ref. 2), one operator of type II turbojet transports (designated turbojet B, in ref. 2), and two operators of type IV turboprop transports (designated only as turboprop in ref. 2). The data for each operator are shown in figure 3 for type I turbojet transports, and in figure 4 for type IV turboprop transports. For comparison the corresponding data for piston-engine airplanes (fig. 1) under nongusty conditions are shown by the crosshatched area in figures 3 and 4. The differences in vertical velocities between some operators were found to be as large as the differences between turbojet and piston-engine aircraft. As may be seen in these figures there is an appreciable variation of the vertical-velocity experience for the various operators, particularly for type I aircraft. (See fig. 3.) One operator of type I aircraft (the sample represented by 122 landings) experienced vertical velocities only slightly higher than those for piston-engine aircraft whereas another operator (106 landings) experienced vertical velocities significantly greater than those of the piston-engine aircraft. For type IV turboprop transports (fig. 4) the vertical velocities experienced by both operators are generally within the range of results shown for piston-engine aircraft.

In order to determine whether, for a given type of aircraft, there is any correlation between sinking speeds at touchdown and several of the known variable conditions of the landings, plots of sinking speed against these variables were made and are given in figures 5 to 9. In figures 5 and 6, sinking speeds are plotted against airspeed at touchdown in terms of speed in knots and percent above stall speed, respectively. The data in these figures are separated according to aircraft type (I, II, and IV). Because of the difference in vertical-velocity experience of a given type of airplane with different operators as previously discussed, the data for the two operators of type I airplanes were separated and are shown in figure 7 as plots of vertical velocity against airspeed at touchdown in terms of percent above stall airspeed. Sinking speeds for the three types of aircraft (I, II, and IV) are also plotted against aircraft landing weight in figure 8 and against distance of touchdown point from runway threshold in figure 9. Examination of figures 5 to 9 shows that in no case is there any strong correlation between sinking speed and any of the variables considered.

Correlation of Vertical Velocities of Piston- and Turbine-Powered Aircraft

As indicated in the preceding sections, the development of larger, heavier, and faster transports has resulted in higher vertical velocities in the case of the turbojet airplanes. In considering the possible causes of these increased sinking speeds there are a number of parameters related to aircraft size, inertia, and controllability which might affect the landing-contact conditions. Some of these parameters are: (1) height of pilot's eyes h above runway with the aircraft in the taxi attitude, (2) horizontal distance l of the pilot from the main landing gear, (3) the parameter $lW_L/C_{L_\alpha}Sq$ which in effect represents the change in pilot's height from runway for a change in normal acceleration, (4) the maximum permissible landing weight W_L, (5) wing loading W_L/S based on maximum permissible landing weight, (6) the mean forward speed at touchdown, and (7) the parameter $V^3C_{m_{\delta_e}}C_{L_\alpha}/4\mu^2\bar{c}k_Y^2$ which is an index of the effectiveness of the elevator in changing the flight-path angle in a given increment of time. (See ref. 6.) The variation of the vertical velocities with these parameters for a number of piston- and turbine-powered transports is shown in figures 10 to 16. In each figure the vertical velocities shown are: (1) the mean vertical velocity and (2) the vertical velocity exceeded, on the average, once in 100 landings. The data for the piston-engine aircraft were obtained from figure 1 and that for the turbine transports, from references 1 and 2.

Consideration of figures 10 to 16 shows that the vertical velocity varies in a fairly consistent manner with each of the parameters except the height of the pilot's eyes h above the runway. (See fig. 10.) As shown in figure 10, the parameter h has remained relatively constant (between 13 and 15 feet) for the airplanes considered and thus any variation of vertical velocity with this parameter would not be detected in the present analysis. The changes in the other parameters (figs. 11 to 16) have been inherently associated with the trend toward large aircraft, and, consequently, the significance of the correlations shown is not easily assessed. Of the several parameters considered, it is thought that the most significant one is the flight-path-control parameter $V^3C_{m_{\delta_e}}C_{L_\alpha}/4\mu^2\bar{c}k_Y^2$. As shown in figure 16, the effectiveness of the elevator in changing the flight-path angle for the turbojet is about 1/3 of that for the turboprop and 1/4 to 1/7 of that for the piston-engine aircraft. This relatively low elevator effectiveness in changing the flight path is thought to be a principal factor in the higher vertical velocities for the turbojets.

Another parameter thought to be of major importance, but secondary to the elevator-effectiveness parameter, in the trend toward higher vertical velocities is the parameter $lW_L/C_{L_\alpha}Sq$. (See fig. 12.) The magnitude of this parameter is indicative of the accuracy with which the pilot could be expected to execute a flare. This parameter is related to changes in pilot's height and normal acceleration as follows:

$$\frac{lW_L}{C_{L_\alpha}Sq} = \frac{l\Delta\alpha}{\frac{\Delta C_L Sq}{W_L}} = \frac{\Delta h}{\Delta a_n}$$

Because of the larger value of the parameter for turbojet transports than for piston-engine transports, a given change in height of the pilot during flare (due to change in angle of attack) would result in a smaller value of normal acceleration for arresting the vertical velocity. Or, conversely, for a given change in normal acceleration the change in height of the pilot (due to change in angle of attack) during the flare would be greater and would tend to make the execution of an intended flare for the turbojet more difficult.

Forward Speed at Touchdown

The forward speed at landing impact for types I and II turbojets, type IV turboprop, and various piston-engine transports is shown in figure 17(a) as the probability of equaling or exceeding a given value of airspeed in percent above stall. The data for the turbine-powered transports are for three operators of type I aircraft, one operator of type II aircraft, and two operators of type IV aircraft. The data for the turbine-powered transports are based on the actual landing weight and are taken from reference 2, whereas the data for the piston-engine transports are based on 90 percent of the maximum landing weight and are taken from references 3 and 4. The stalling speeds used were in all cases those given in operations manuals for the particular aircraft. The frequency distributions of figure 17(b) for turbine-powered and piston-engine transports were based on mean curves for the range of turbine and piston-engine data of figure 17(a), respectively. The data of figure 17 show that the touchdown speeds for the three turbine-powered transports lie within a band of about 5 percent of the stalling speed with respect to each other and, in comparison with the results for the piston-engine airplanes, indicate less variation in the landing speeds. In this connection, a detailed study of the data showed that the mean speeds (in percent above stall speed) were approximately the same for the piston- and turbine-powered airplanes, but that the standard deviation from the mean was much less for the turbine transports than for the piston-engine airplanes. It appears, therefore, that the touchdown speeds for the turbine transports are more precisely controlled than those for the piston-engine transports.

Effect of Various Factors on Forward Speed at Touchdown

In order to show the effect of operators on touchdown speeds, probability curves showing the touchdown speeds in terms of the stalling speed are presented in figure 18 for two operators of type I aircraft and in figure 19 for two operators of type IV aircraft. For type I aircraft one operator touched down on the average, about 5 percent of the stall speed lower than the other operator. It may be mentioned that this is the operator that had an appreciably higher vertical velocity at impact as discussed in a previous section. (See fig. 3.) For type IV aircraft, the two operators landed at an airspeed that was approximately the same percentage above the stalling speed.

The variation of touchdown speed with landing weight and the distance of the point of touchdown from the runway threshold is shown in figures 20, 21, and 22 for types I, II, and IV turbine-powered transports. The data of figure 20 show a general variation of airspeed at touchdown with aircraft weight but at any given weight there is an appreciable variation in airspeed. As may be expected the data of figures 21 and 22 show a random variation of airspeeds with distance of the touchdown point from the runway threshold.

VGH DATA

Landing-Impact Accelerations Obtained From VGH Data

The landing-impact accelerations for types I, II, and III turbojet transports and types IV, V, and VI turboprop transports are shown in figure 23 as the probability of equaling or exceeding given values of normal acceleration measured near the center of gravity. The data in figure 23 for all turbine-powered aircraft except type VI are from two or more aircraft of the same type. In addition the data for aircraft types I, II, and IV include two or more operators. Also shown in figure 23 for comparison are impact accelerations experienced by several different types of piston-engine transports (indicated by the crosshatched area in the figure). The VGH data show that except for aircraft type VI, the impact accelerations have about the same distribution for the various turbine-powered aircraft and are appreciably higher than those for the piston-engine transports. The impact accelerations for aircraft type VI fell within the limits indicated for piston-engine transports.

Effect of Various Parameters on Impact Accelerations

In order to determine what effect pilot experience had on impact accelerations encountered, data covering about 2 years of operation of one type of turbojet aircraft by one operator were divided into two periods, each about a year in duration. The first period covered 400 landings and the second period, 409 landings. These data are shown in figure 24. There appears to be a slight difference in the impact acceleration experienced in the two periods. Since statistically the impact accelerations may be related to vertical velocities, these data indicate that the vertical velocities at impact would be about the same for the two periods. This result is in agreement with those reported in reference 2 wherein vertical velocities were measured with a camera on one type of turbojet transport during two different periods 8 months apart.

The effect of operator on the landing-impact accelerations is shown in figures 25 and 26. The data in figure 25 are for four operators of type II aircraft. Appreciable differences in the impact-acceleration experience may be noted for the various operators. One operator (curve for 377 landings), in particular, experienced impact accelerations on the average about 0.1g lower than the other operators. The data in figure 26 are for three operators of type IV turboprop transports. Two of the operators have about the same impact-acceleration experience, whereas the third operator shows a somewhat higher acceleration experience. The higher accelerations for this operator may not be indicative of extended operations, however, inasmuch as the data sample is small.

The variation of impact acceleration for types I and II aircraft with the parameters: (1) forward speed at touchdown in knots and percent above stall, (2) vertical acceleration immediately prior to touchdown (type I only), (3) landing gross weight, and (4) the normal-force coefficient C_N immediately prior to impact (type I only) is presented in figures 27 to 34. Examination of these figures indicates that little or no correlation exists between impact acceleration and the various parameters.

Forward Speeds at Touchdown

The forward speeds at touchdown for types I and II turbojet transports are presented in figure 35 as the probability of equaling or exceeding a given speed in percent above stall speed. The percent above stall speed was computed on the assumption that the vertical acceleration immediately prior to impact was 1.0g. (That this assumption is satisfactory may be seen in fig. 36, where the airspeed in percent above stall computed on this basis agrees closely with that computed by including the vertical acceleration in the determination of stall speed.) The data in figure 35 are for three operators of type II aircraft and one operator of type I aircraft. Based on the VGH data in figure 35, the touchdown speeds of type II aircraft are in general lower than those for type I aircraft by about 10 percent of the stall speed. Based on camera measurements the touchdown speeds for type II aircraft were found to be about 5 percent lower than those for type I aircraft. (See fig. 17.) The difference between the two sets of data may be due to the camera data representing operations at one airport and in clear weather only, whereas the VGH data represent operations at many airports and under various weather conditions.

Effect of Operator and Aircraft Weight on Touchdown Speed

The effect of operator on touchdown speeds of type II turbojet transports is shown in figure 37 for three operators. One of the operators (34 landings) was touching down about 5 percent of the stall speed higher than the other two operators. This operator (34 landings) experienced about 0.1g lower impact acceleration than the other operator. (See curves of fig. 25 with corresponding symbols.)

The variation of touchdown speed with aircraft weight for types I and II turbojet transports is shown in figures 38 and 39. As a matter of possible interest, lines corresponding to $1.1V_S$, $1.2V_S$, $1.3V_S$, and $1.4V_S$ are shown in the figures. Although the touchdown speeds show an overall tendency to increase with weight, there are large variations in the speeds at any given weight. In general, there appears to be little correlation of touchdown speed with weight.

CONCLUDING REMARKS

The analysis of camera and VGH data on landing-contact conditions has shown that from the overall viewpoint, turbojet transports experienced vertical velocities about 25 percent higher than those experienced by piston-engine transports. Vertical velocities for turboprop airplanes do not appear to be substantially different from the experience of the piston-engine transports. Large differences in the vertical-velocity experiences exist between operations of a given type of airplane, thus indicating that the operator can have an appreciable effect on the landing-contact experience.

Correlation of vertical velocities for all classes of commercial transports (piston, turboprop, and turbojet) has shown that vertical velocity at landing impact varied in a fairly consistent manner with aircraft weight, wing loading, distance of the pilot forward of the landing gear, mean touchdown speed, and the effectiveness of the elevator in controlling the flight path. It is suspected that a principal factor in the higher vertical velocities for the turbojet transports is the relatively low effectiveness of the elevator in changing the flight path in a given interval of time (1/3 to 1/7 of the elevator effectiveness of turboprop and piston-engine aircraft).

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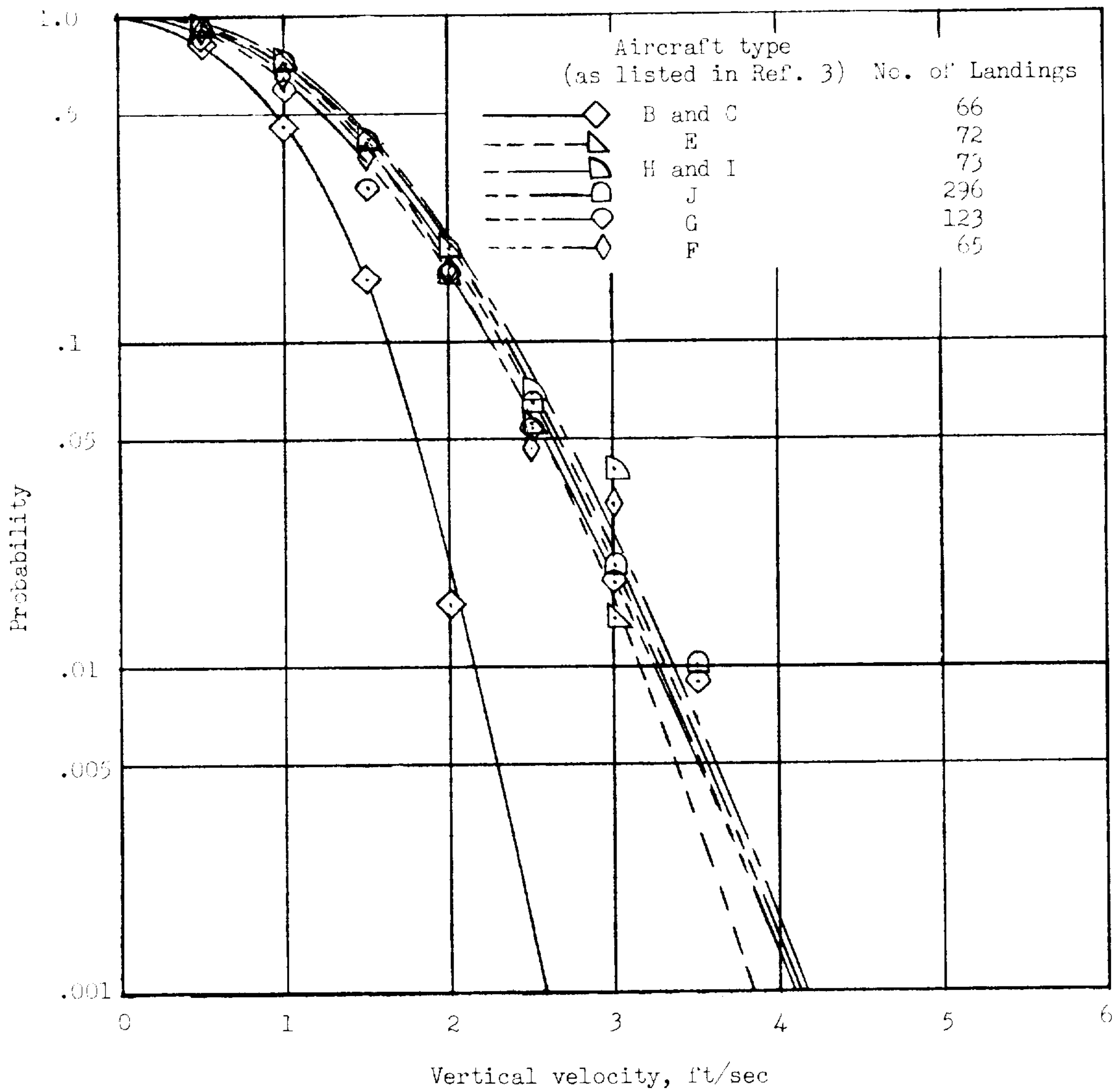


Figure 1.- Probability distributions of vertical velocity at landing impact for various types of piston-engine transports. Camera data.

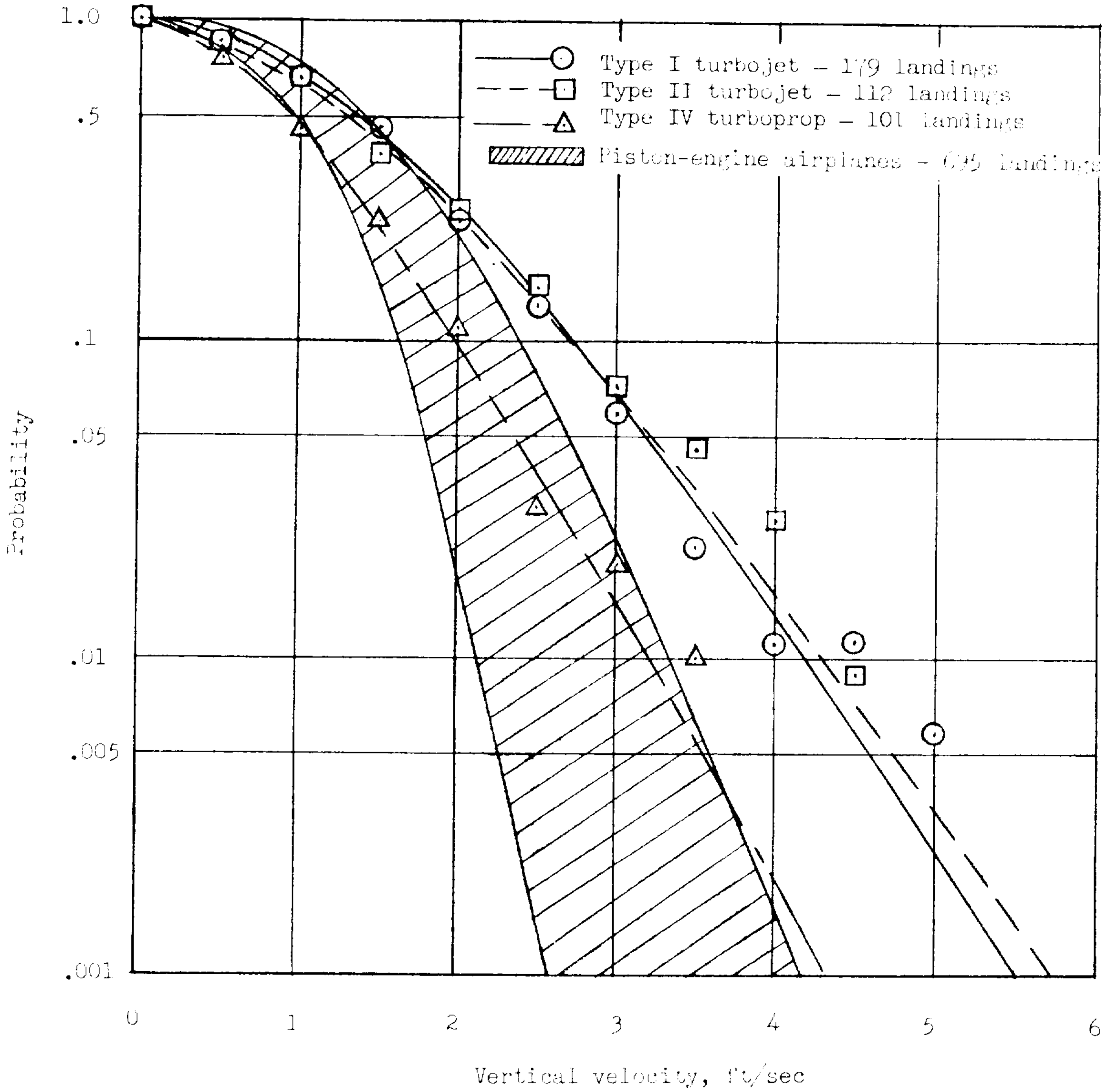


Figure 2.- Comparison of probability distributions of vertical velocity at landing impact for two turbojet transports, a turboprop transport, and a range of values for piston-engine transports. Camera data.

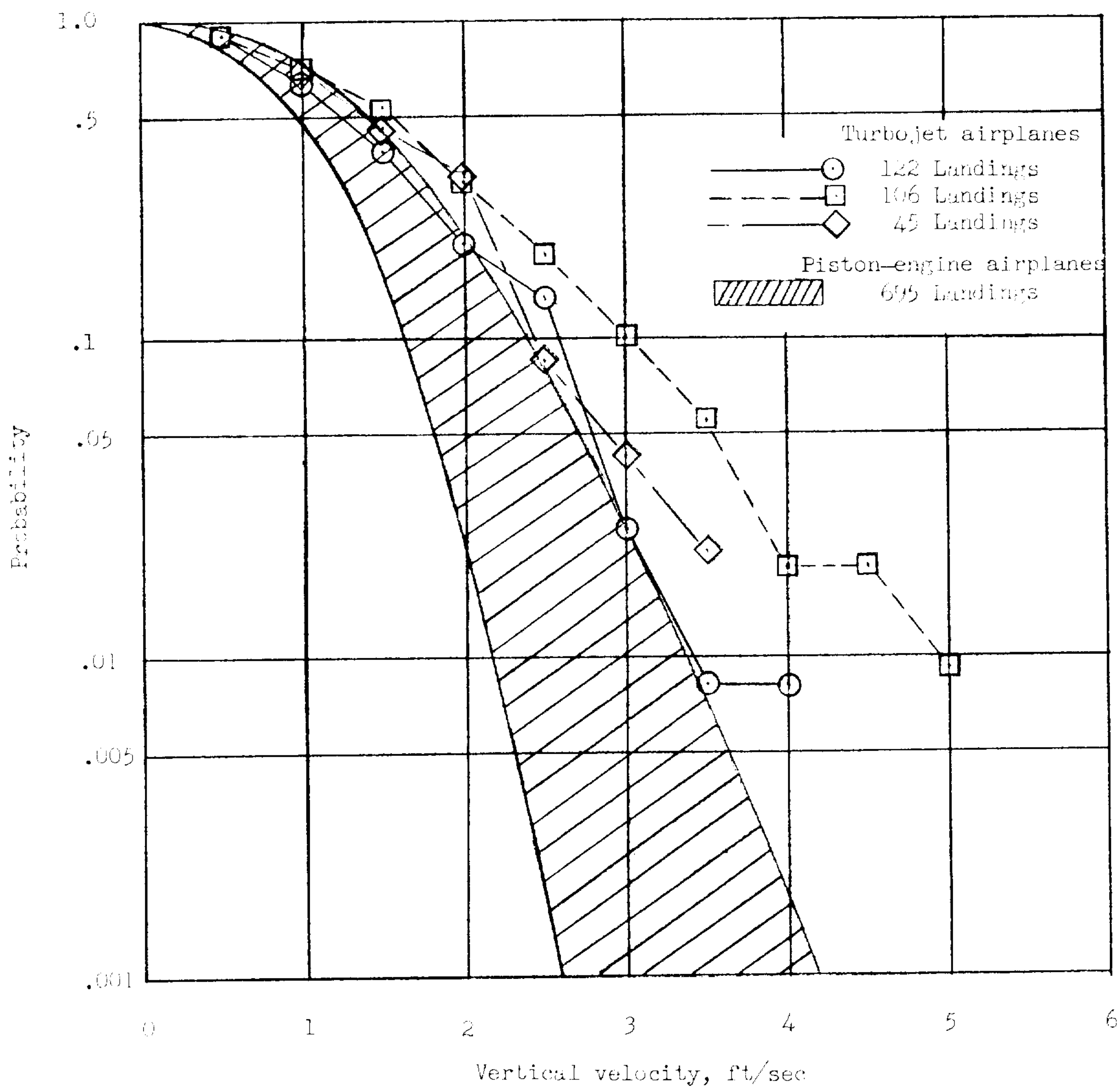


Figure 3.- Comparison of probability distributions of vertical velocity at landing impact for three operators of type I turbojet transports and a range of values for piston-engine transports. Camera data.

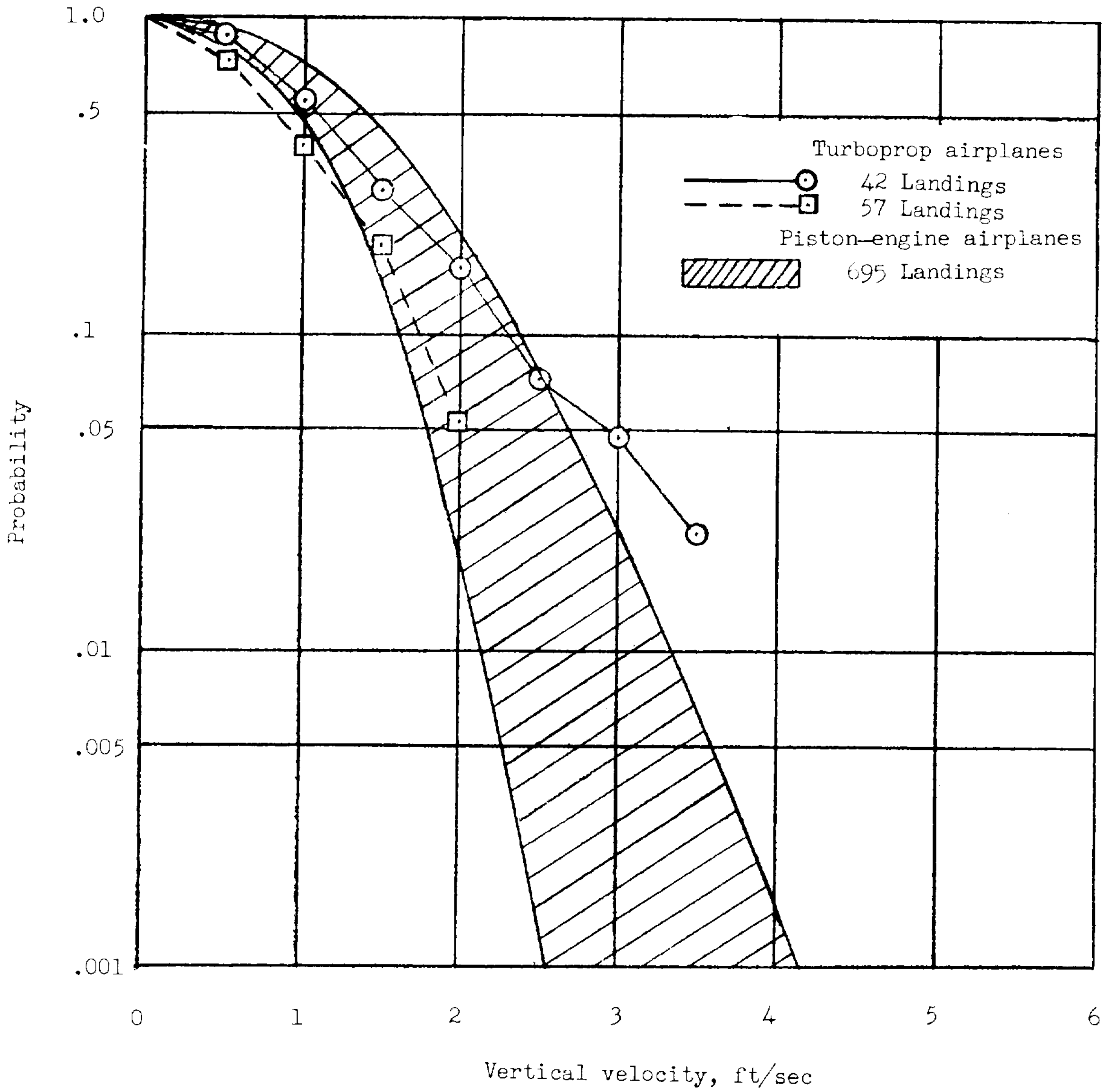
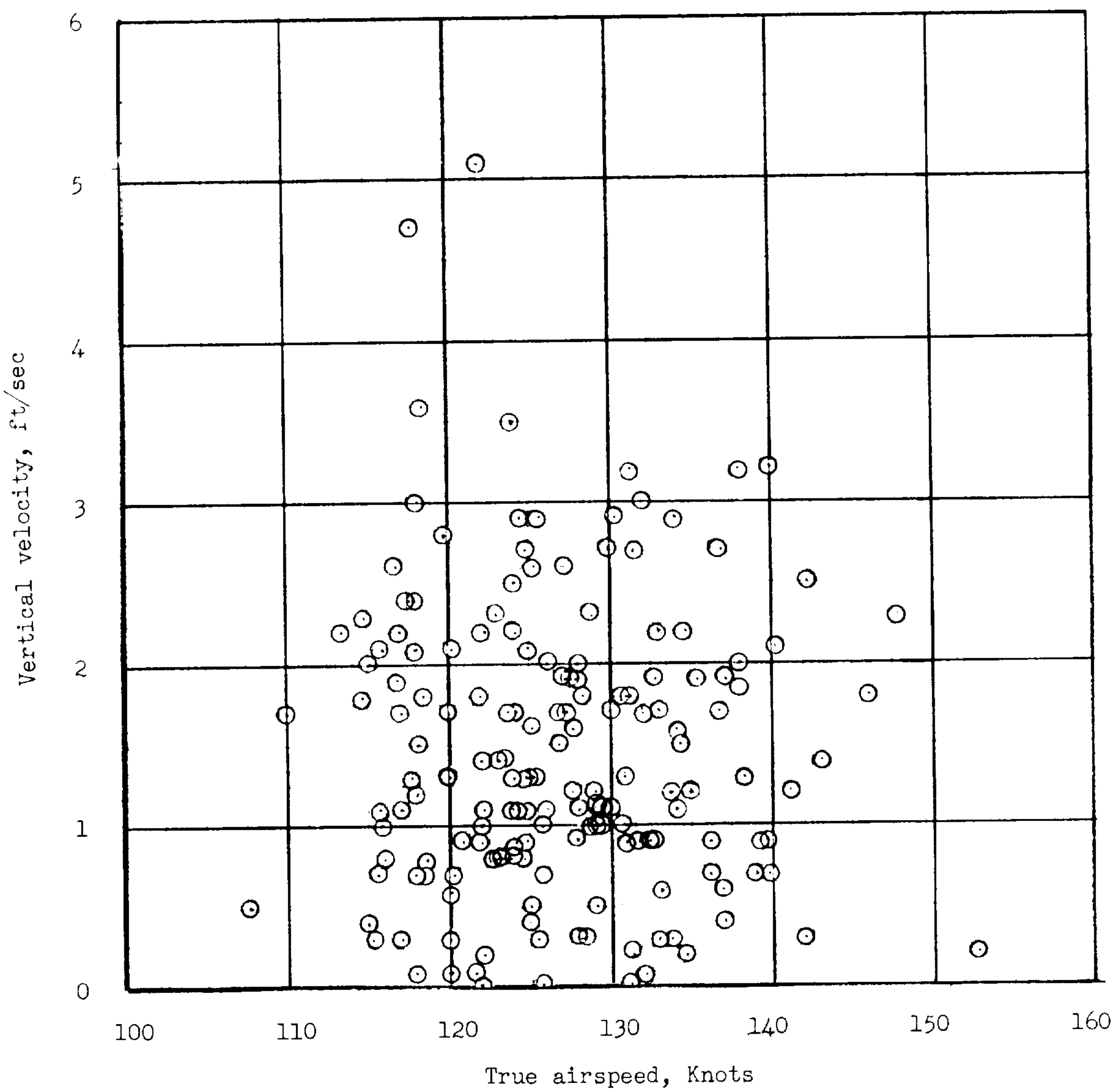
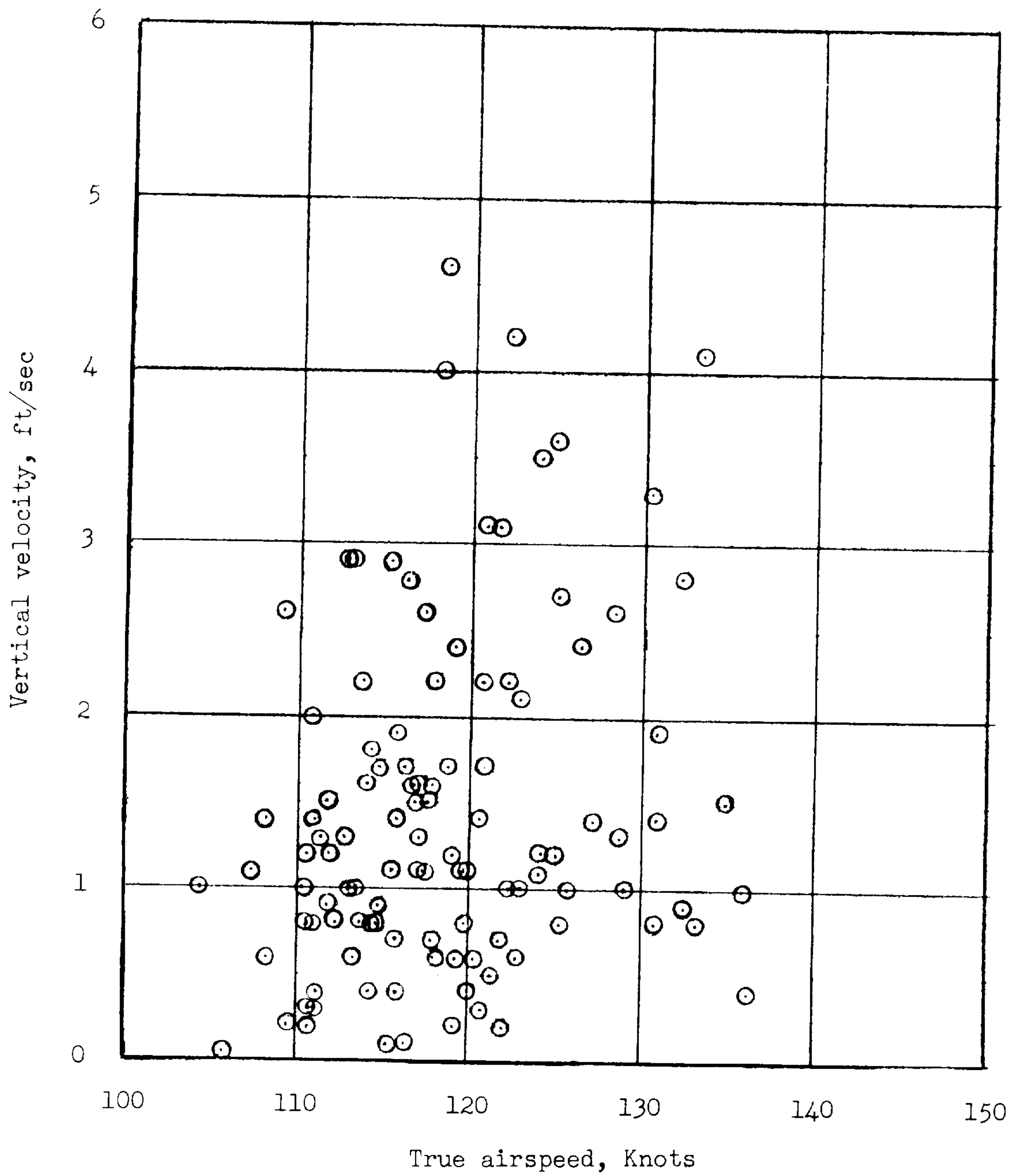


Figure 4.- Comparison of probability distributions of vertical velocity at landing impact for two operators of type IV turboprop transports and a range of values for piston-engine transports. Camera data.



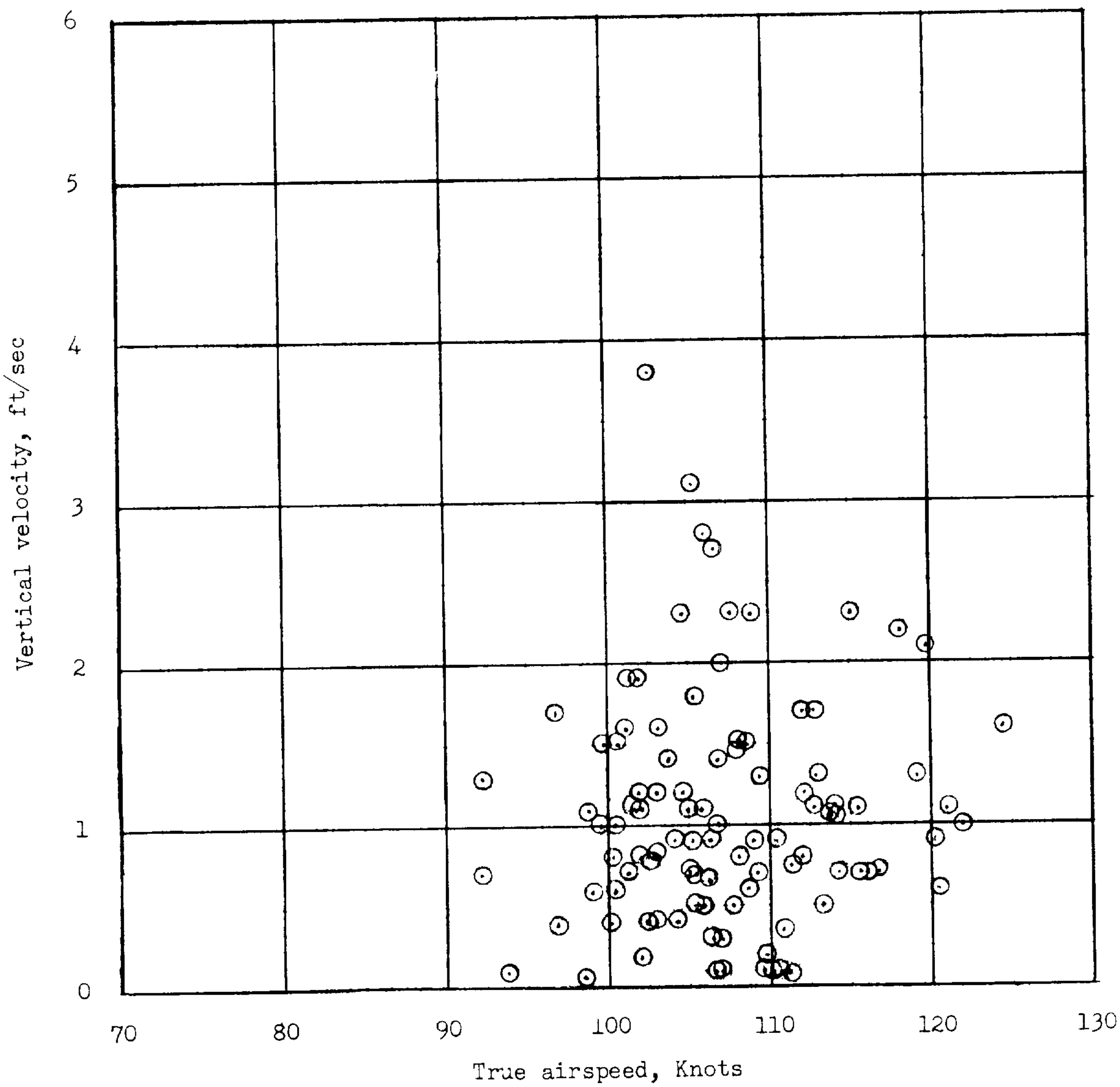
(a) Type I.

Figure 5.- Variation of vertical velocity with airspeed in knots at touchdown for three turbine-powered transports. Camera data.



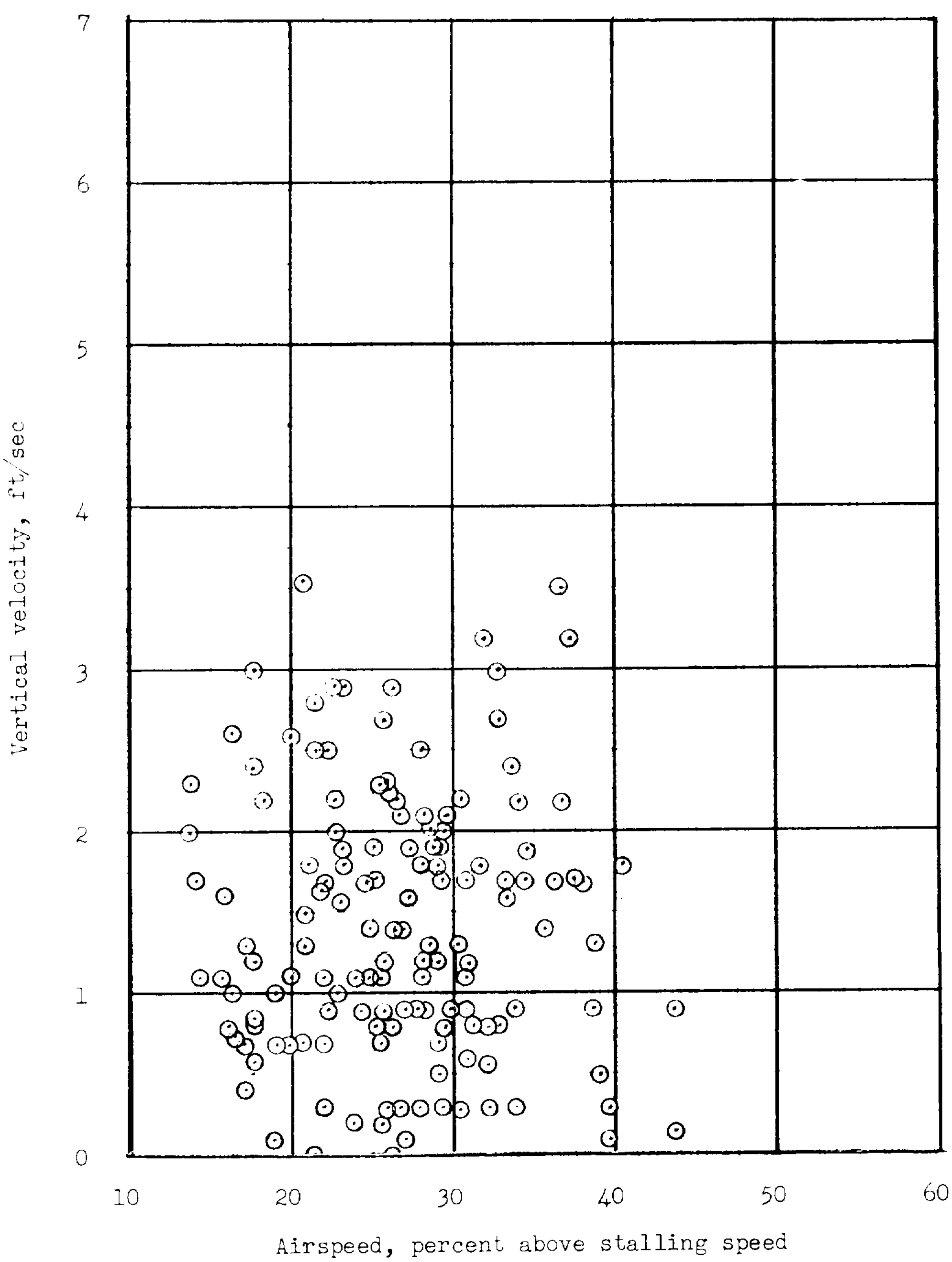
(b) Type II.

Figure 5.- Continued.



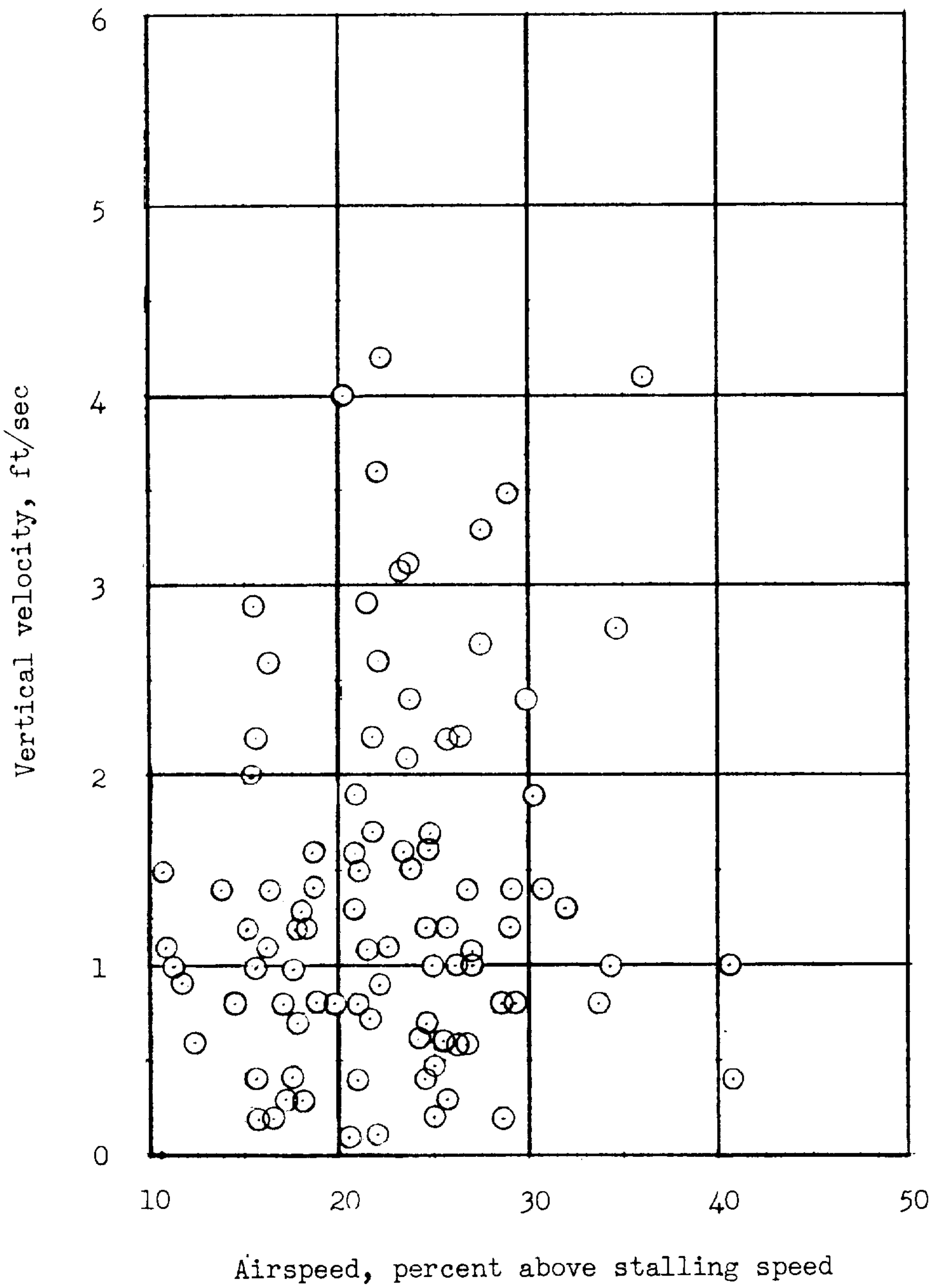
(c) Type IV.

Figure 5.- Concluded.



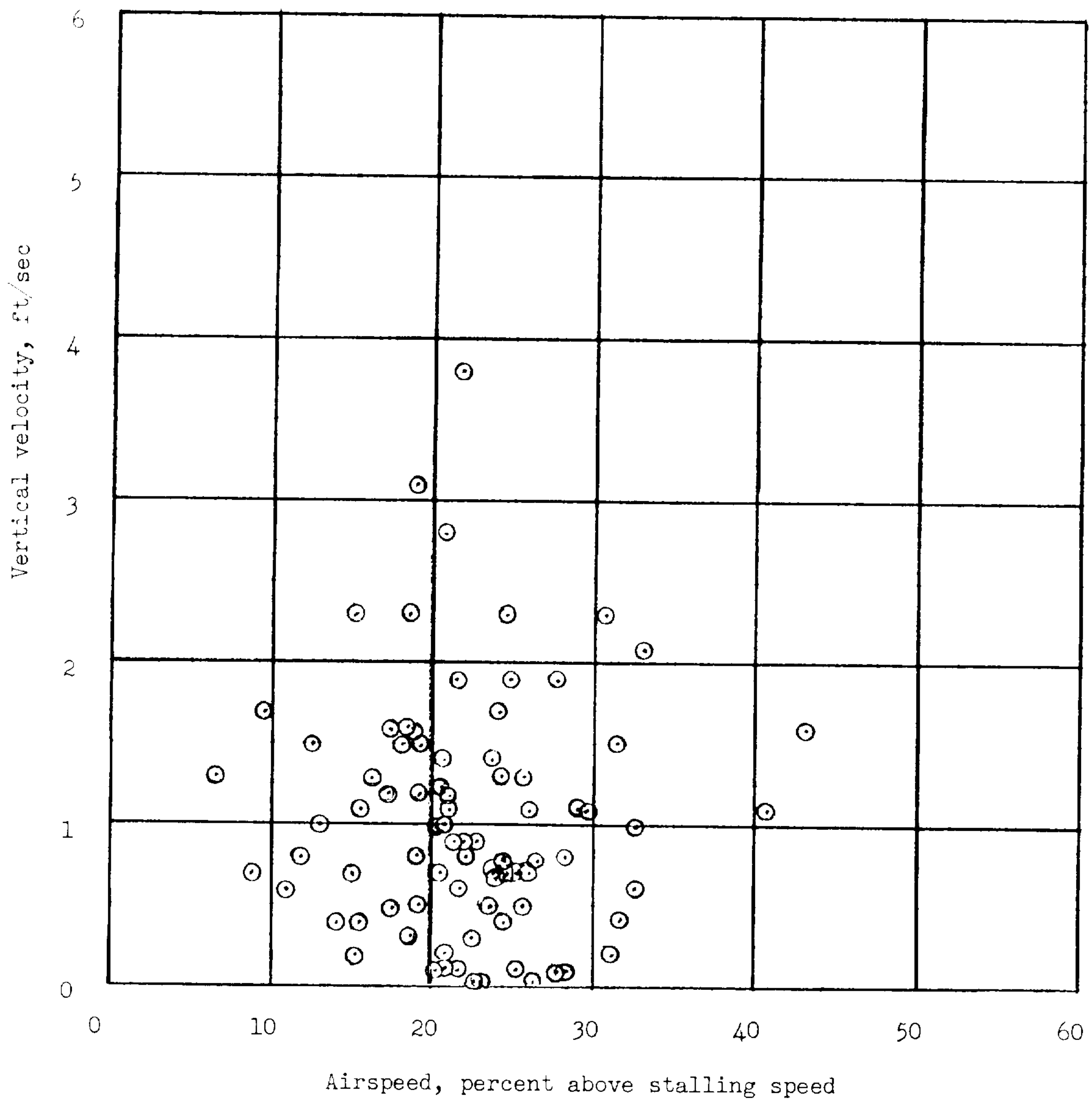
(a) Type I.

Figure 6.- Variation of vertical velocity with airspeed in percent above stalling speed at touchdown for three turbine-powered transports. Camera data.



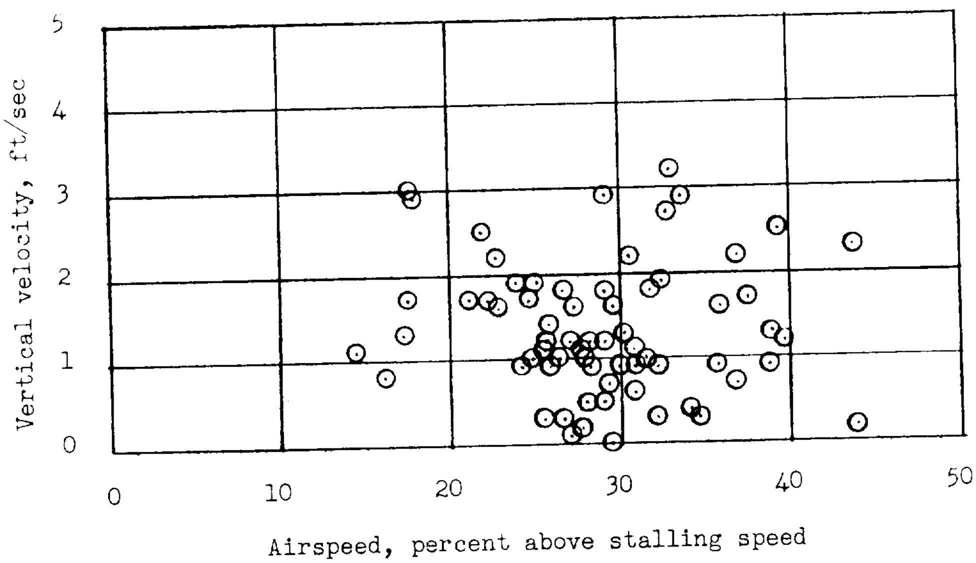
(b) Type II.

Figure 6.- Continued.

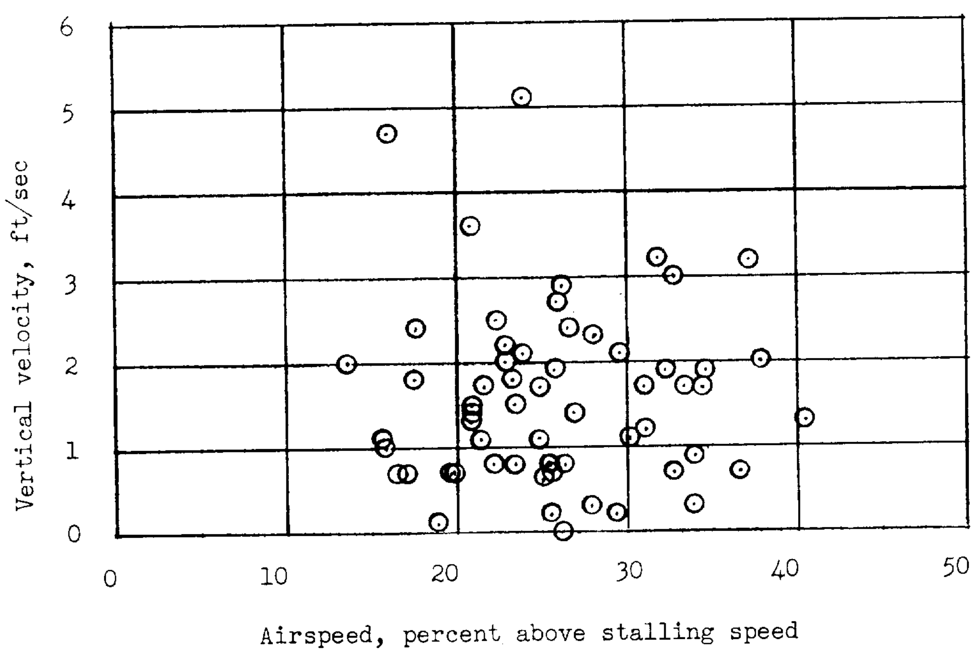


(c) Type IV.

Figure 6.- Concluded.

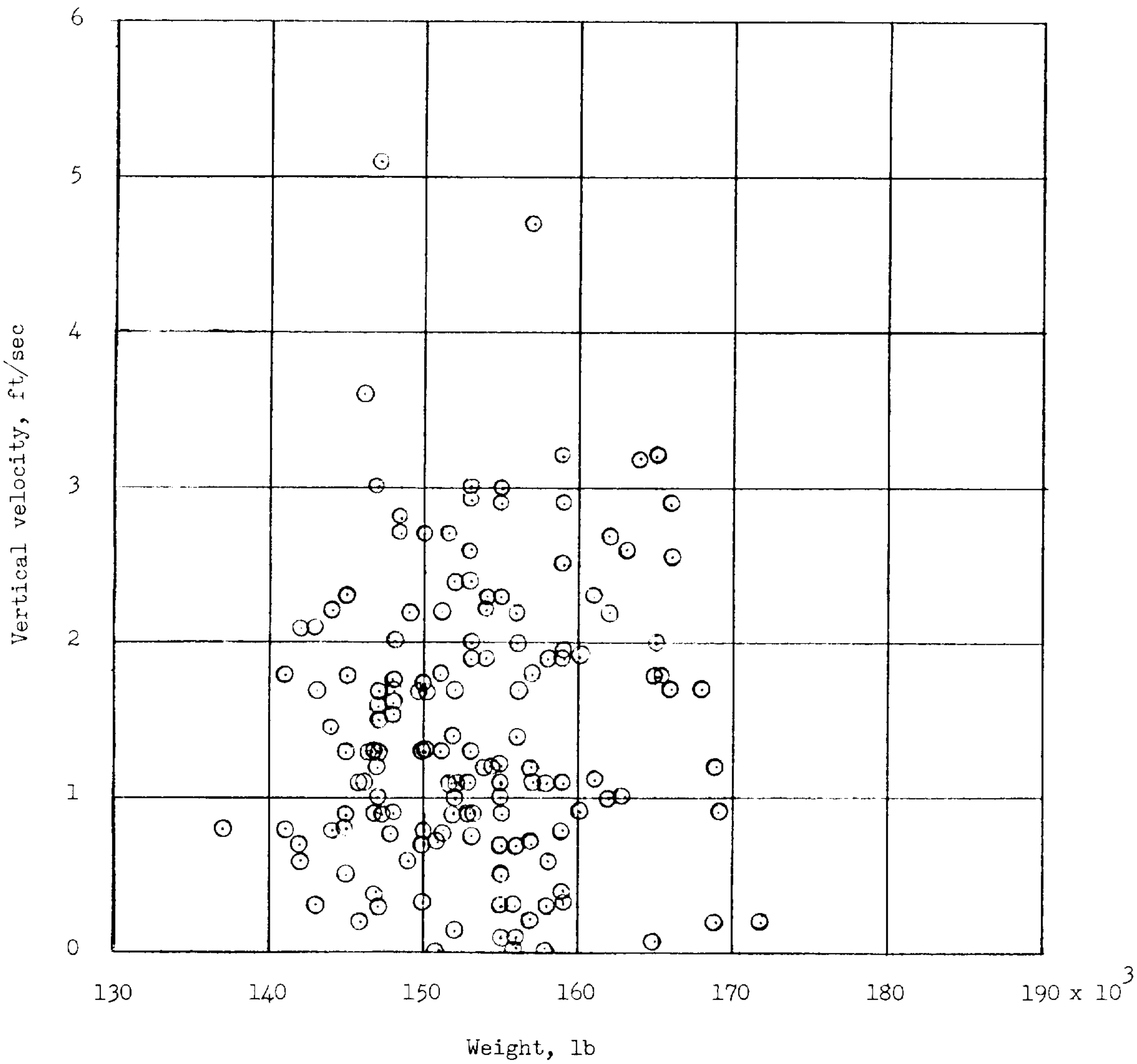


(a) Operator A.



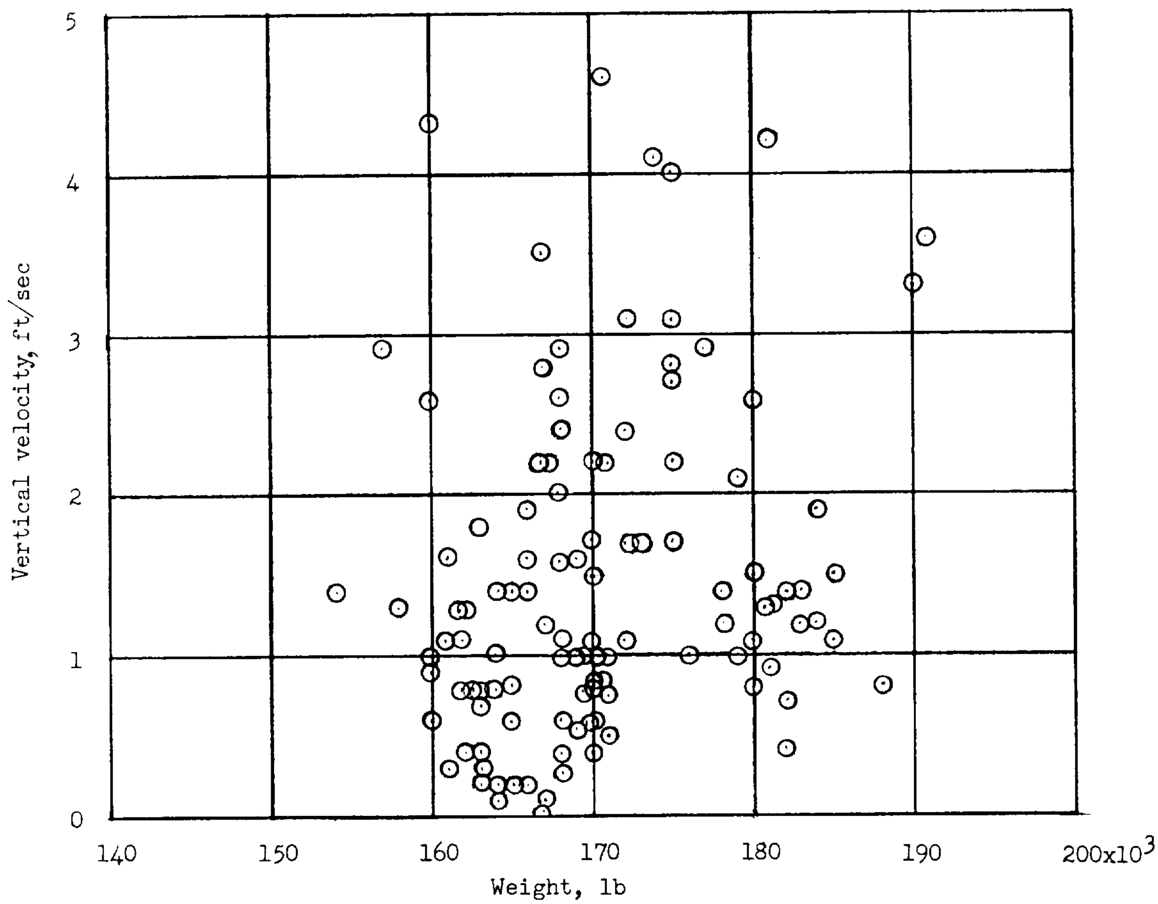
(b) Operator B.

Figure 7.- Variation of vertical velocity with airspeed in percent above stalling speed at touchdown for two operators of type I transports. Camera data.



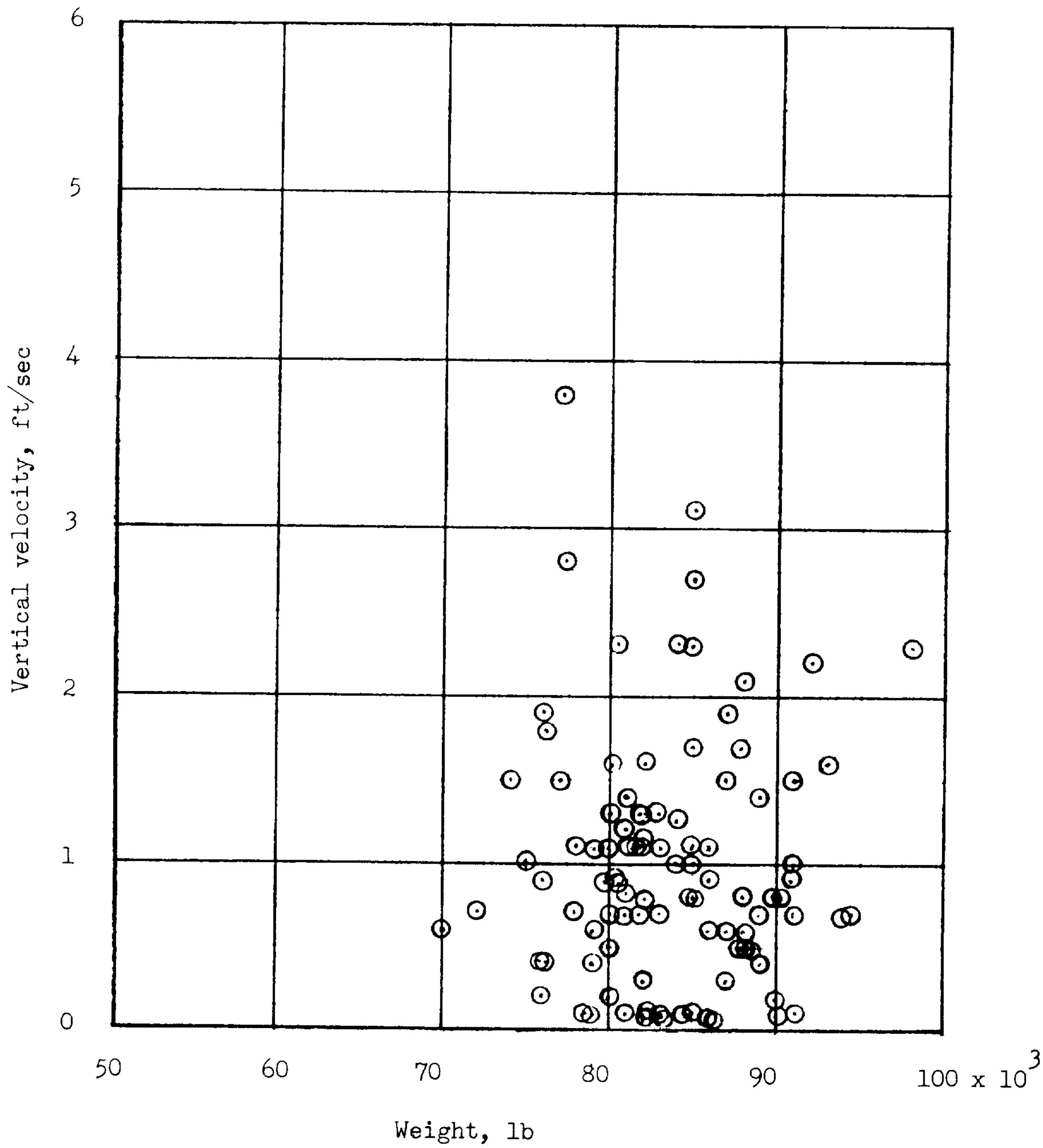
(a) Type I.

Figure 8.- Variation of vertical velocity at touchdown with landing weight for three turbine-powered transports. Camera data.



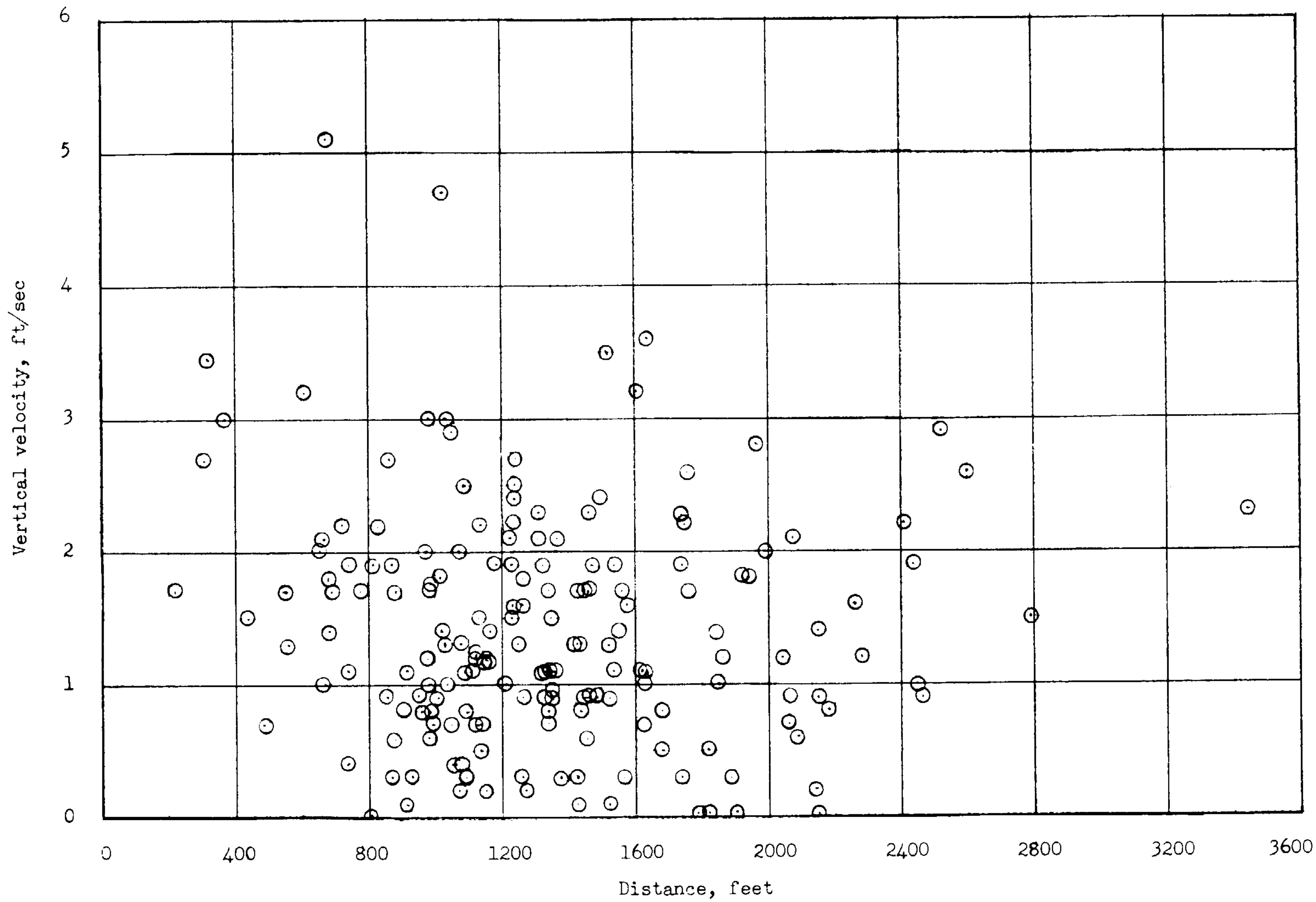
(b) Type II.

Figure 8.- Continued.



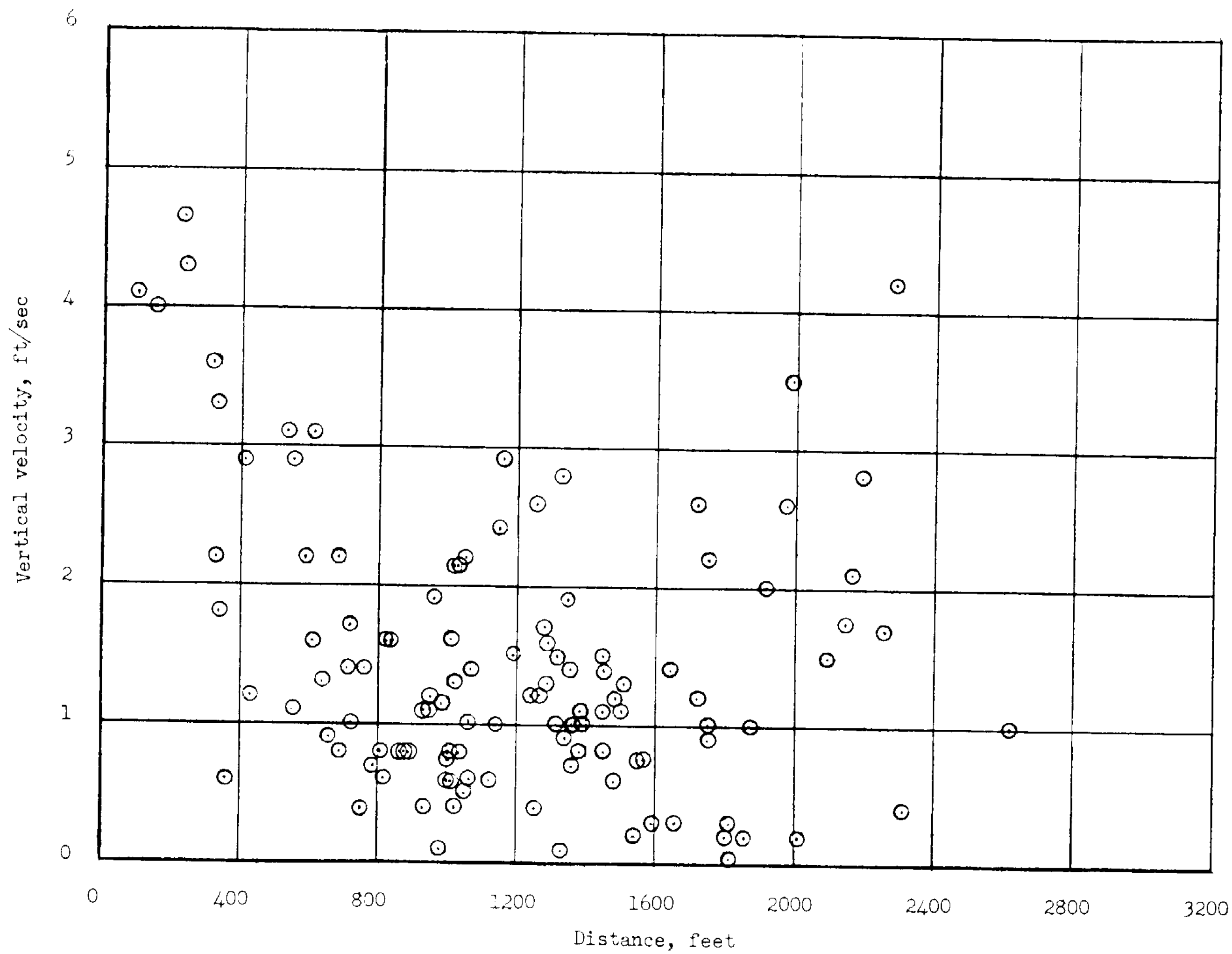
(c) Type IV.

Figure 8.- Concluded.



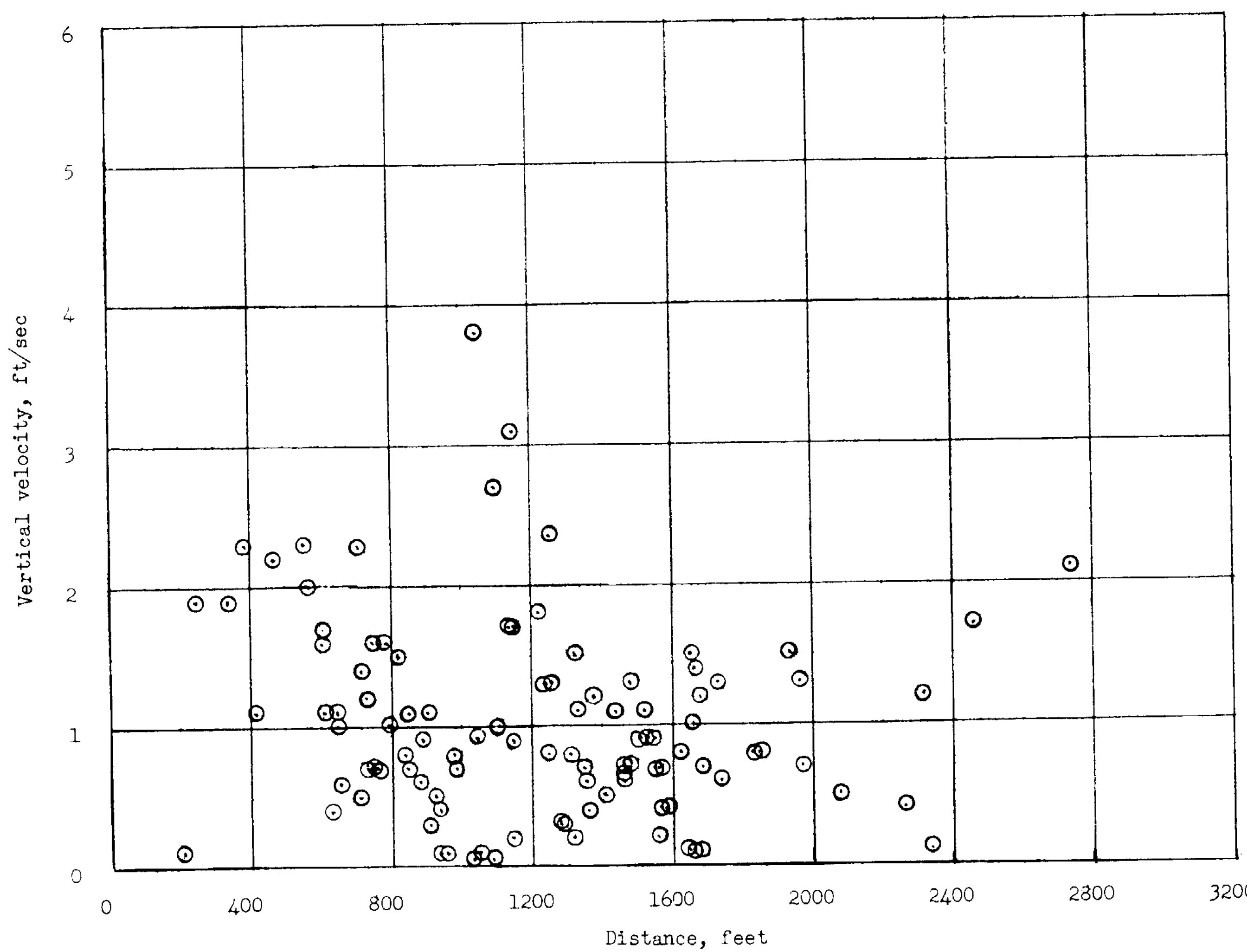
(a) Type I.

Figure 9.- Variation of vertical velocity with distance from the runway threshold at touchdown for three turbine-powered transports. Camera data.



(b) Type II.

Figure 9.- Continued.



(c) Type IV.

Figure 9.- Concluded.

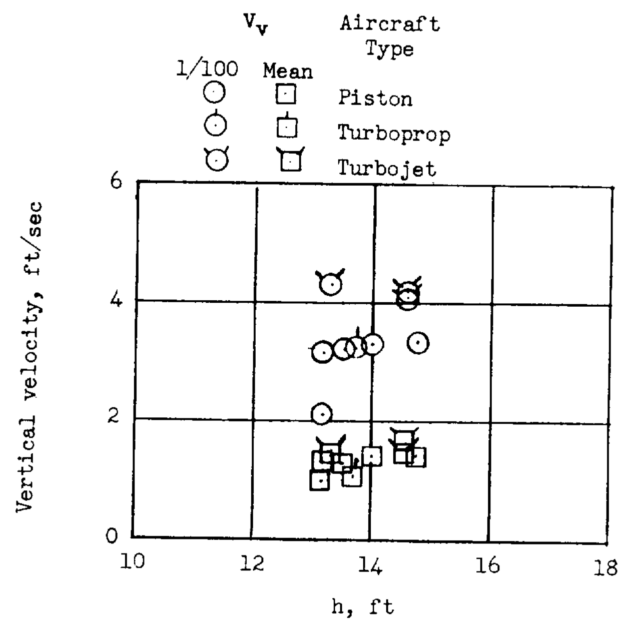


Figure 10.- Variation of $\bar{V}_V$ and V_V with h for a probability of 1 in 100 landings for three types of aircraft. Camera data.

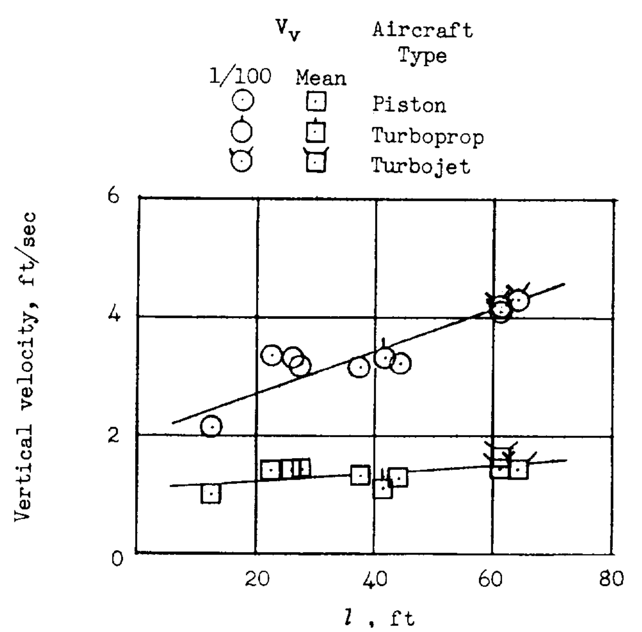


Figure 11.- Variation of $\bar{V}_V$ and V_V with l for a probability of 1 in 100 landings for three types of aircraft. Camera data.

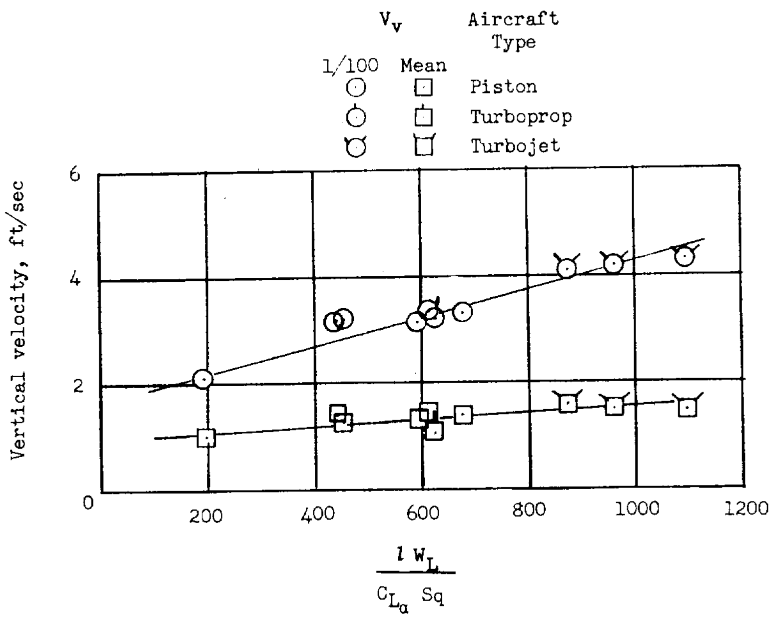


Figure 12.- Variation of $\overline{V}_V$ and V_V with the parameter $lW_L/C_{L_\alpha}Sq$ for a probability of 1 in 100 landings for three types of aircraft. Camera data.

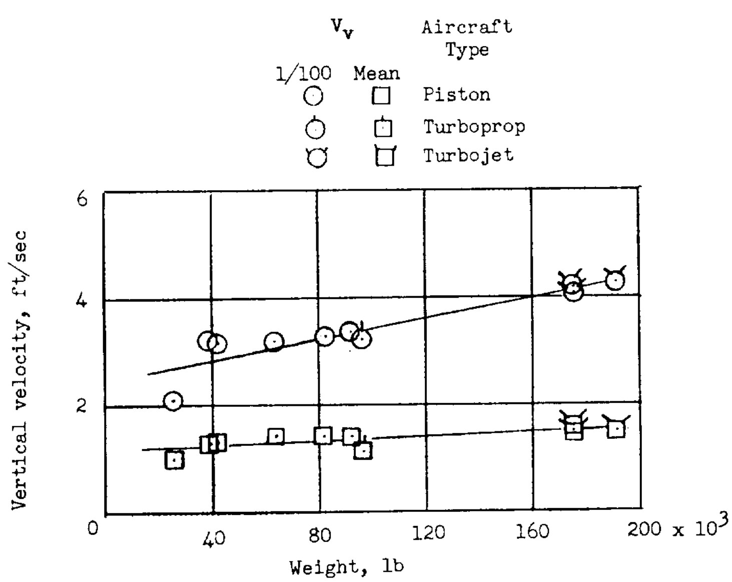


Figure 13.- Variation of $\overline{V}_V$ and V_V with landing weight (max. permissible) for a probability of 1 in 100 landings for three types of aircraft. Camera data.

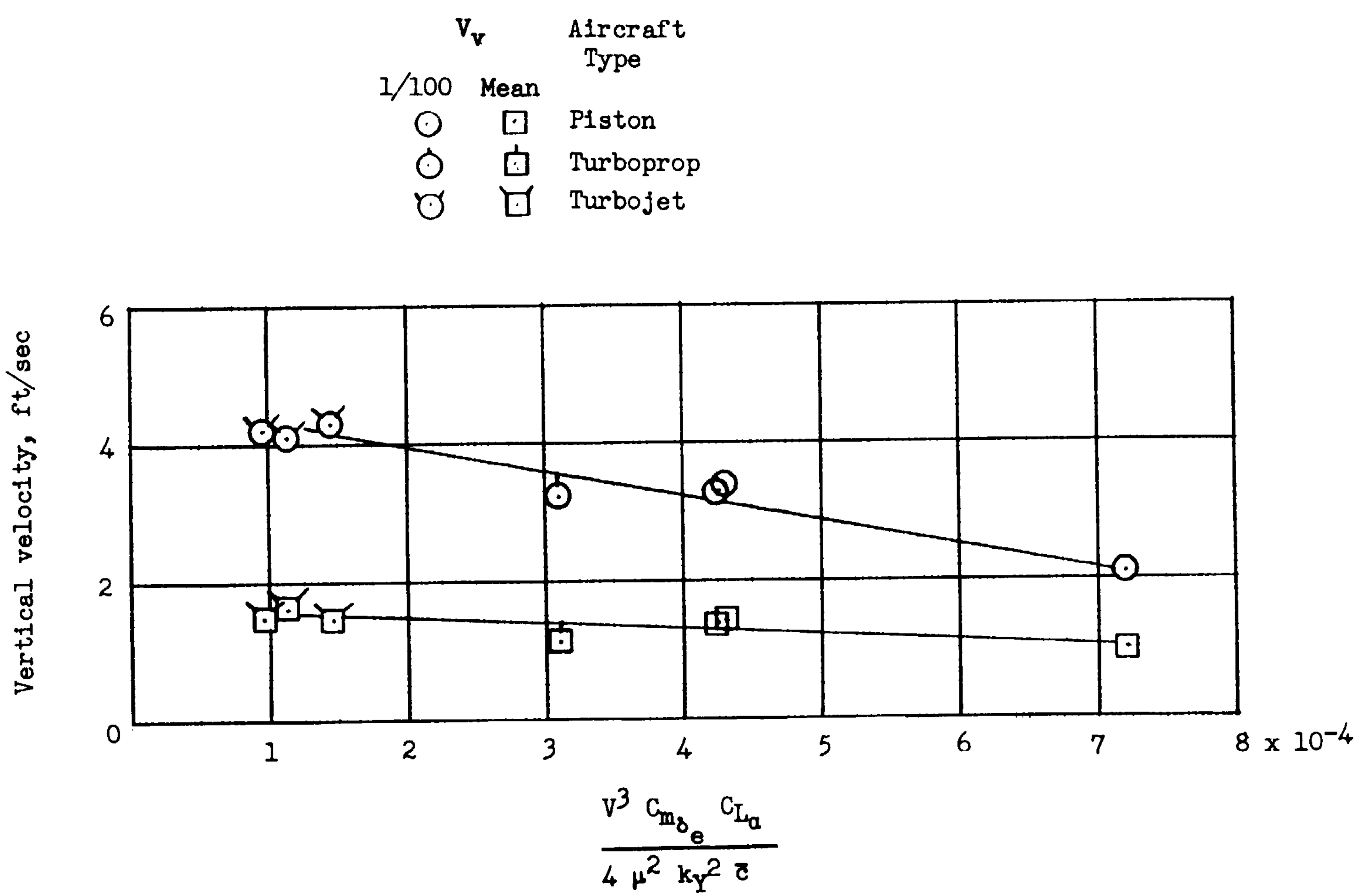


Figure 16.- Variation of $\bar{V}_v$ and V_v with flight-path-control parameter for a probability of 1 in 100 landings for three types of aircraft. Camera data.

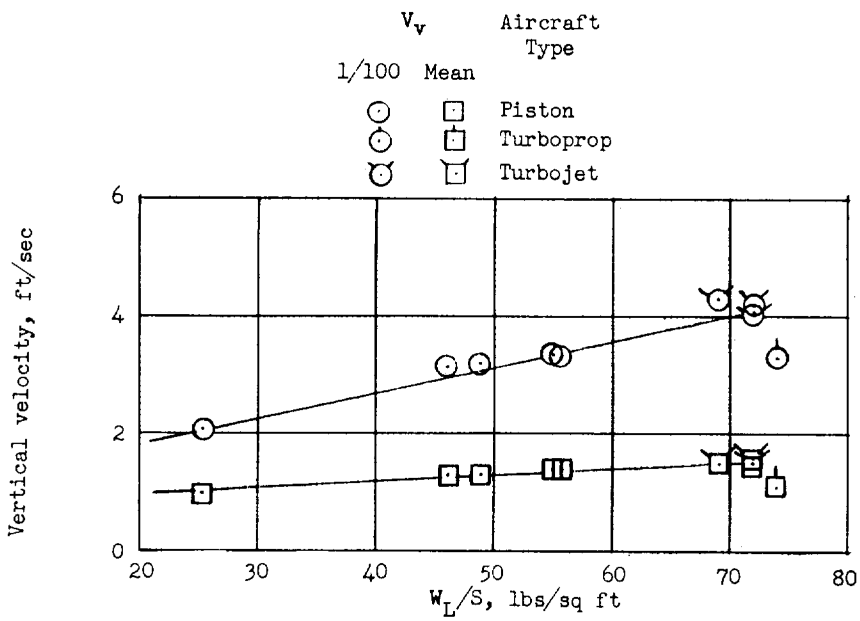


Figure 14.- Variation of $\overline{V}_V$ and V_V with wing loading for a probability of 1 in 100 landings for three types of aircraft. Camera data.

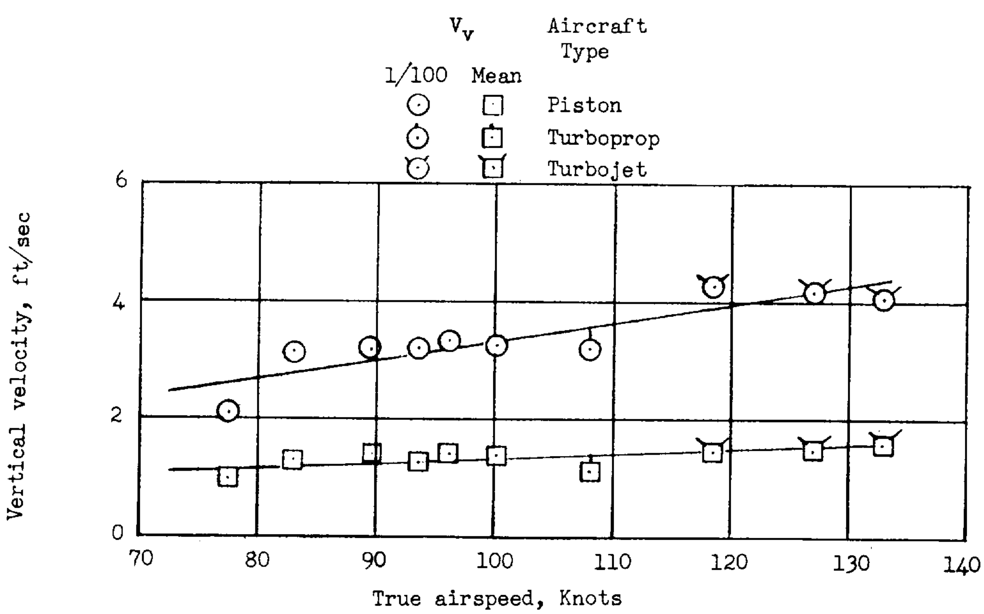


Figure 15.- Variation of $\overline{V}_V$ and V_V with airspeed at touchdown for a probability of 1 in 100 landings for three types of aircraft. Camera data.

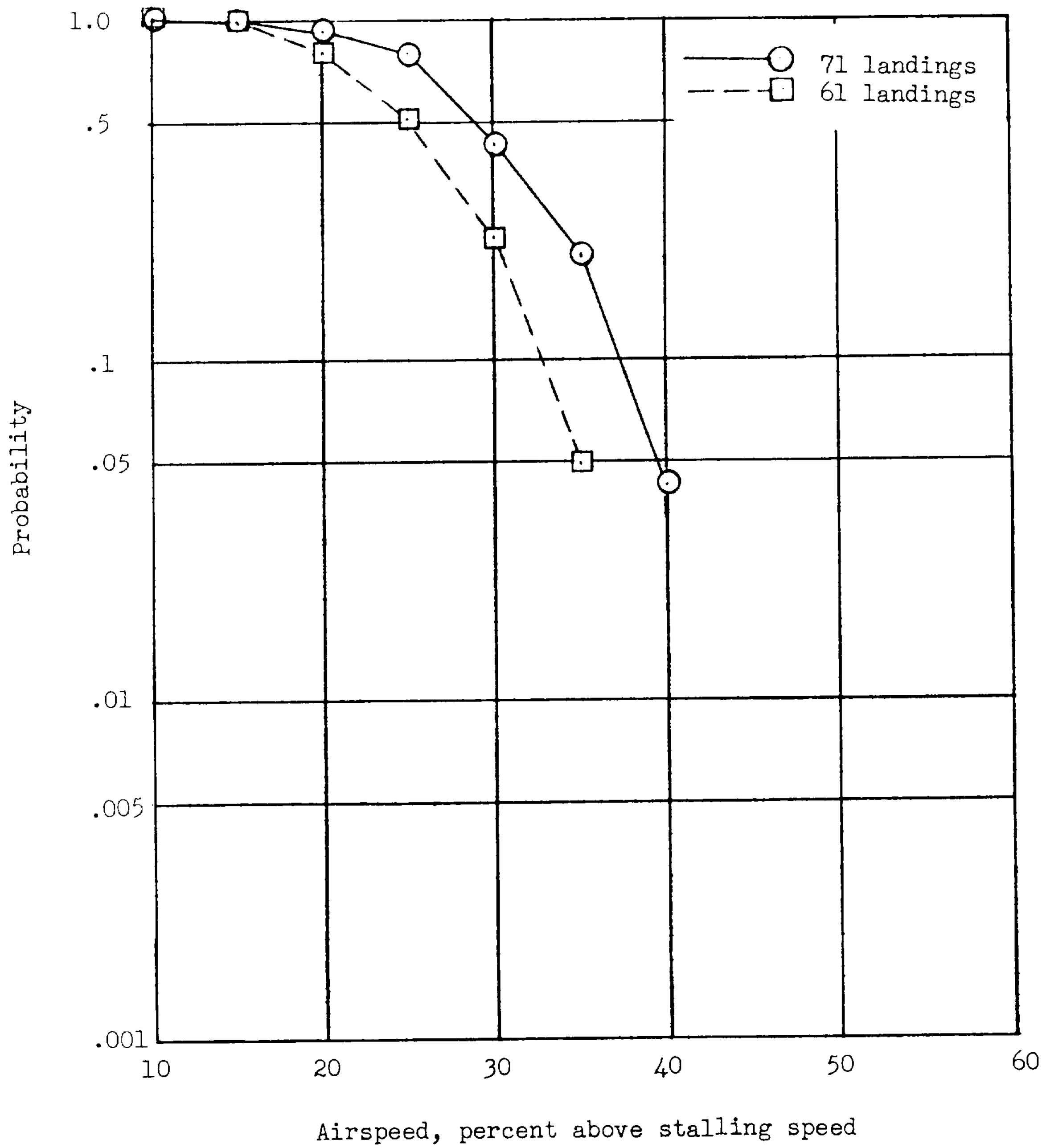
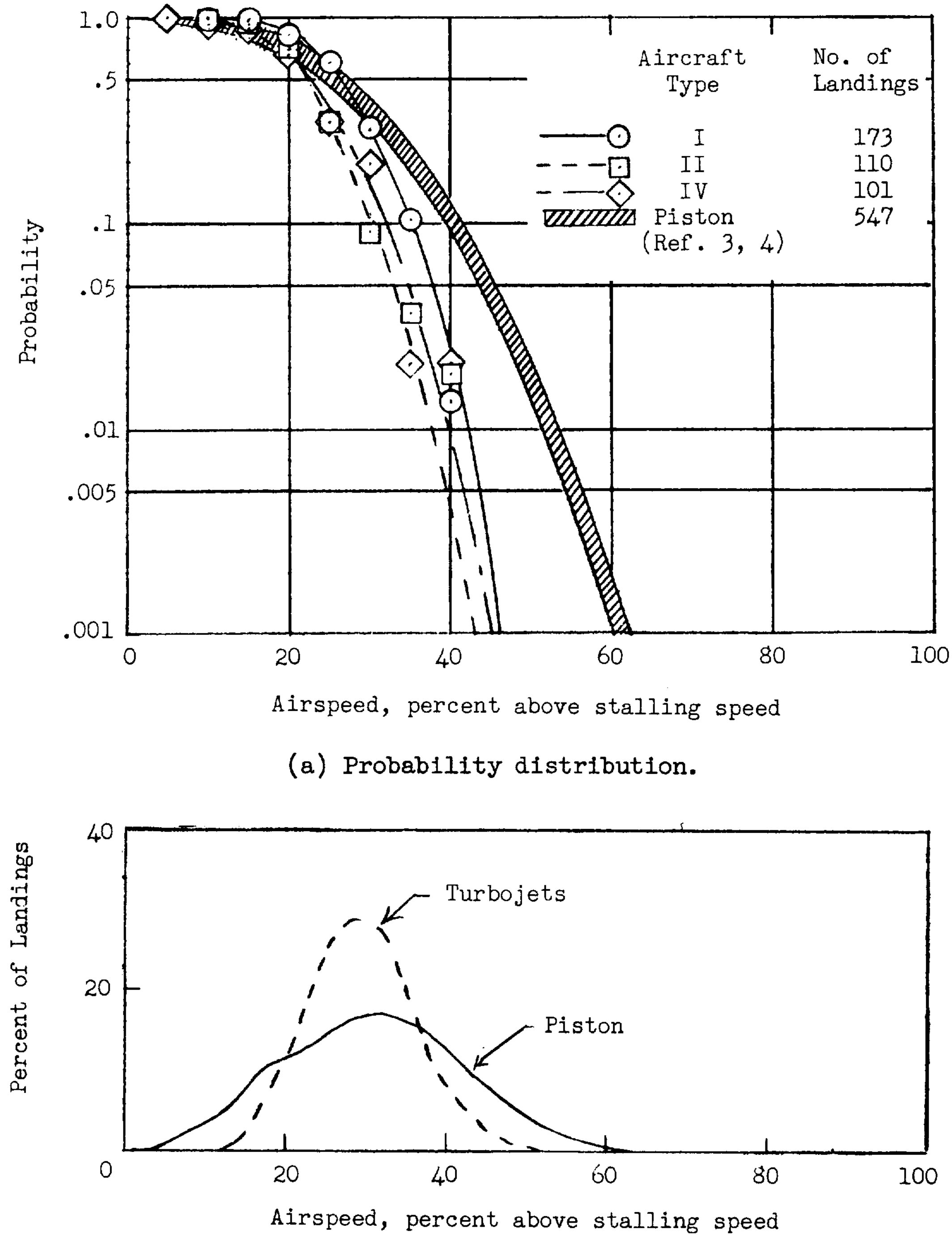


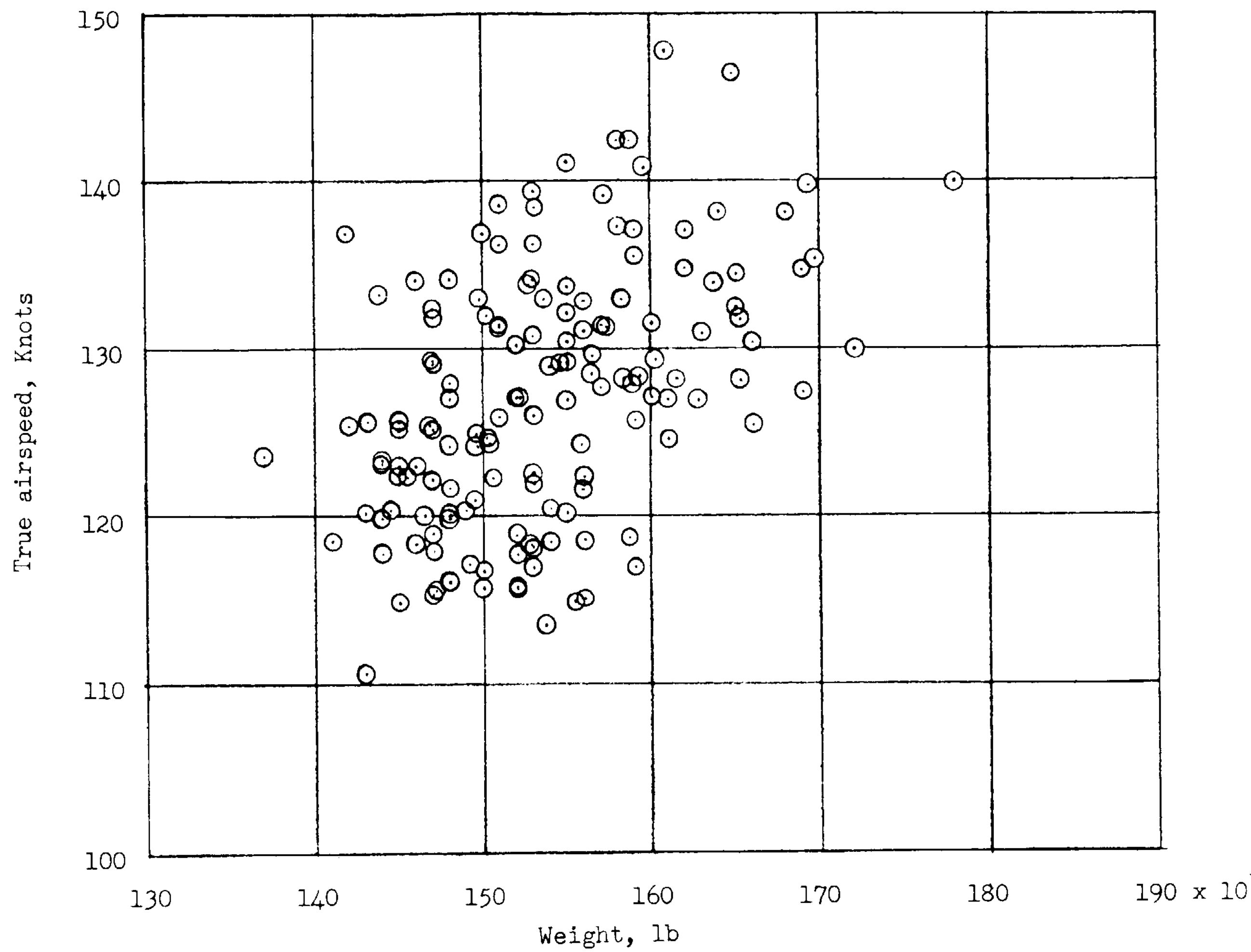
Figure 18.- Probability distributions of airspeed in percent above stalling speed at touchdown for two operators of type I turbojet transports. Camera data.



(a) Probability distribution.

(b) Frequency distribution.

Figure 17.- Airspeed in percent above stalling speed for three turbine-powered transports and a number of piston-engine transports. Camera data.



(a) Type I.

Figure 20.- Variation of airspeed at touchdown with landing weight for three types of turbine-powered transports. Camera data.

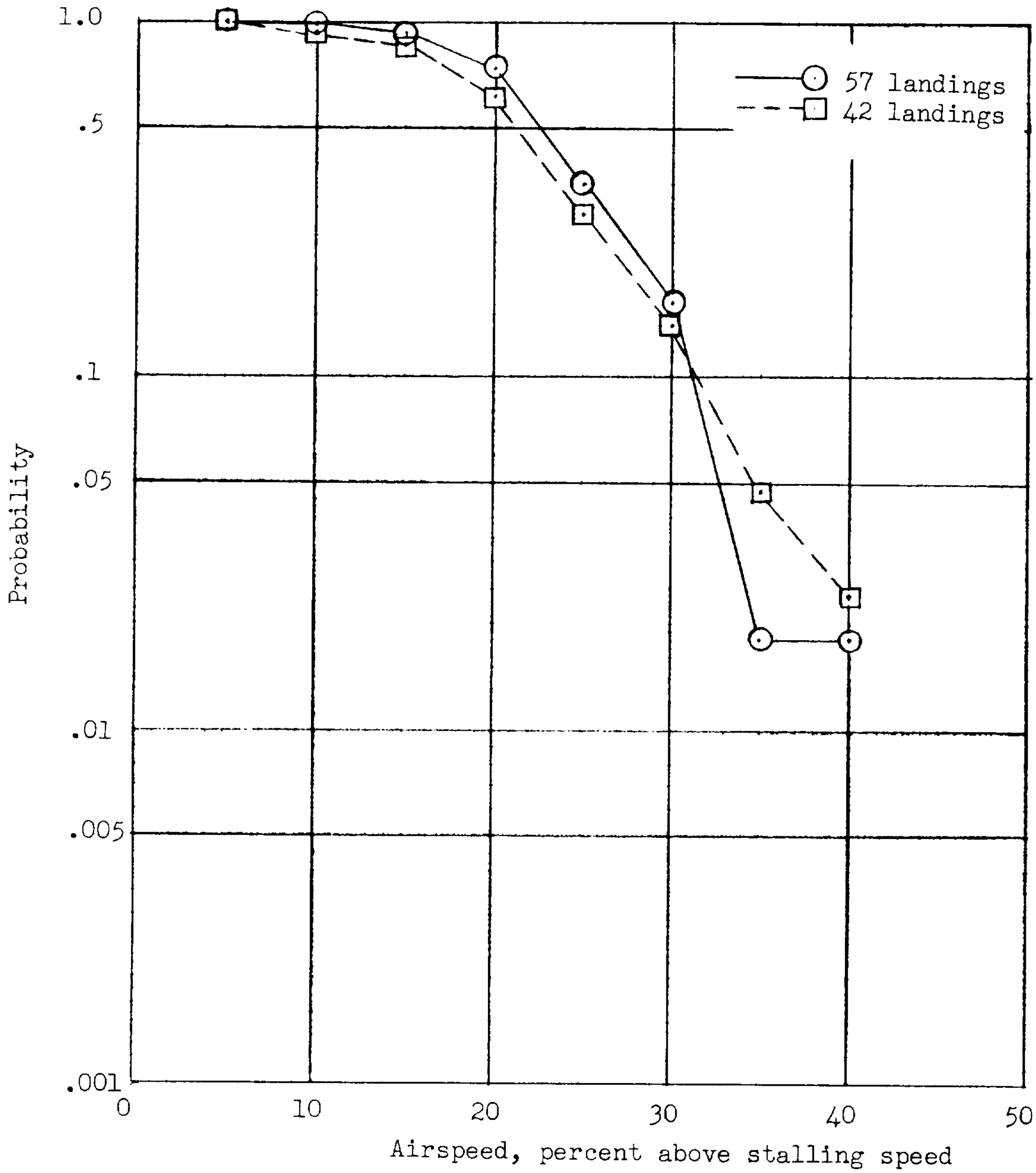
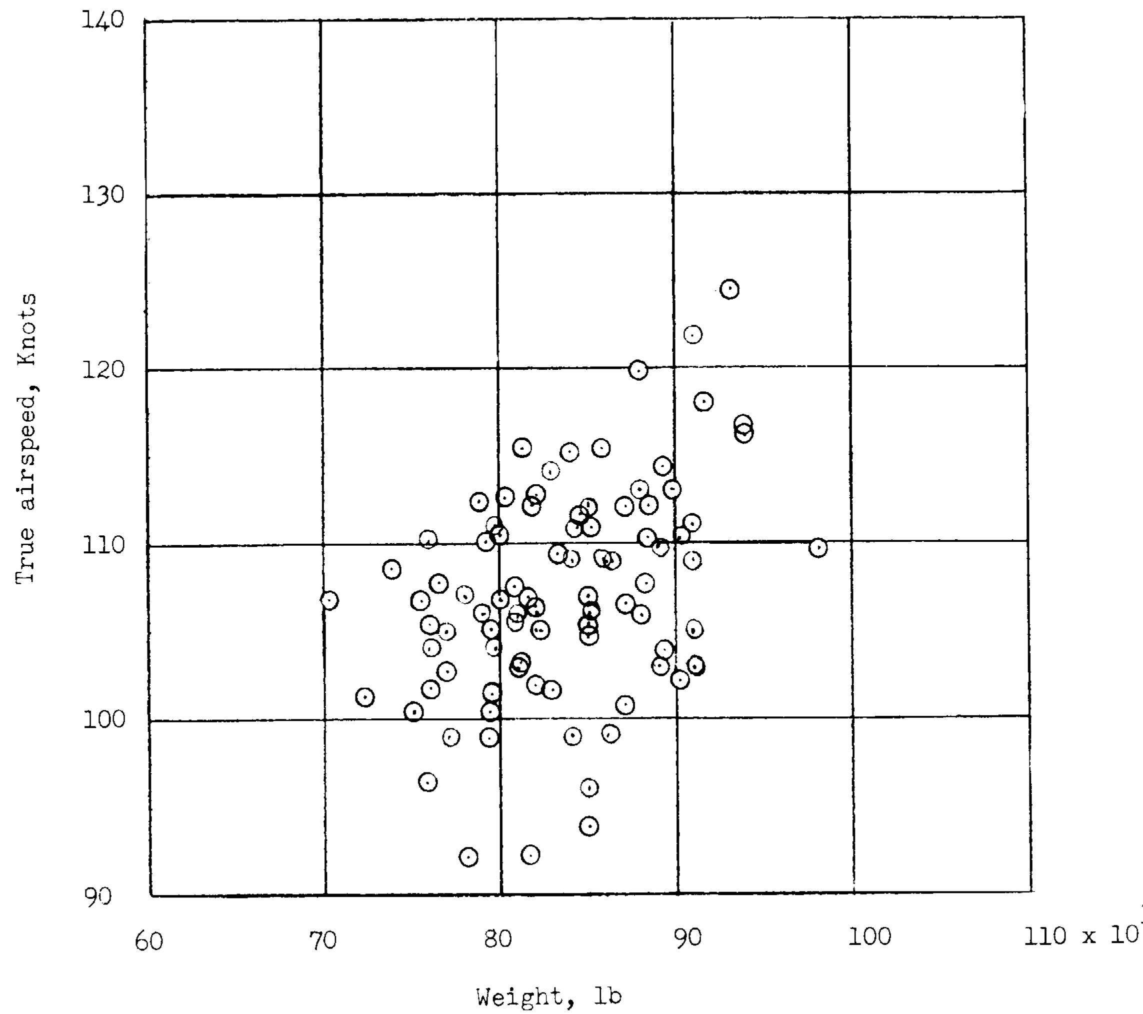
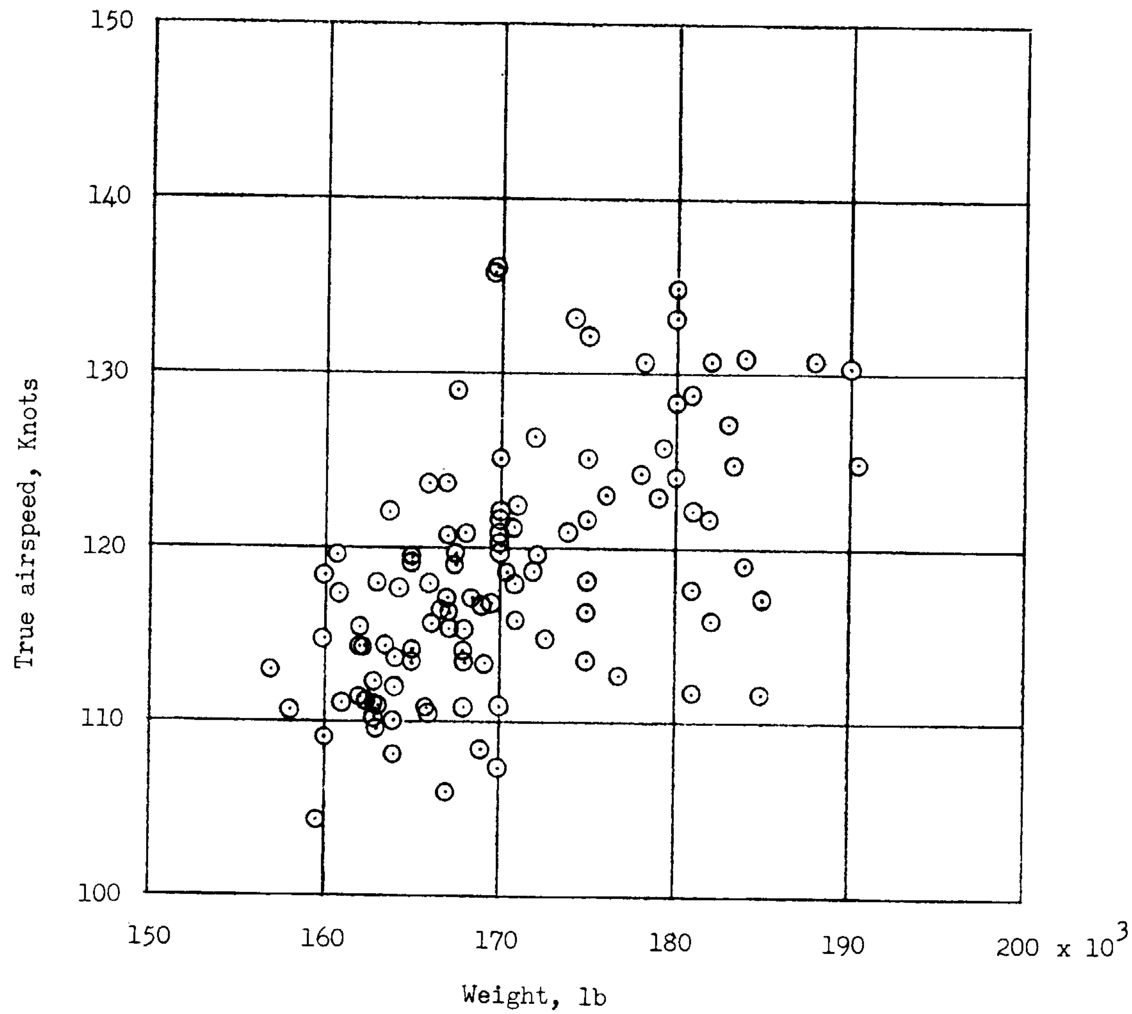


Figure 19.- Probability distributions of airspeed in percent above stalling speed at touchdown for two operators of type IV turboprop transports. Camera data.



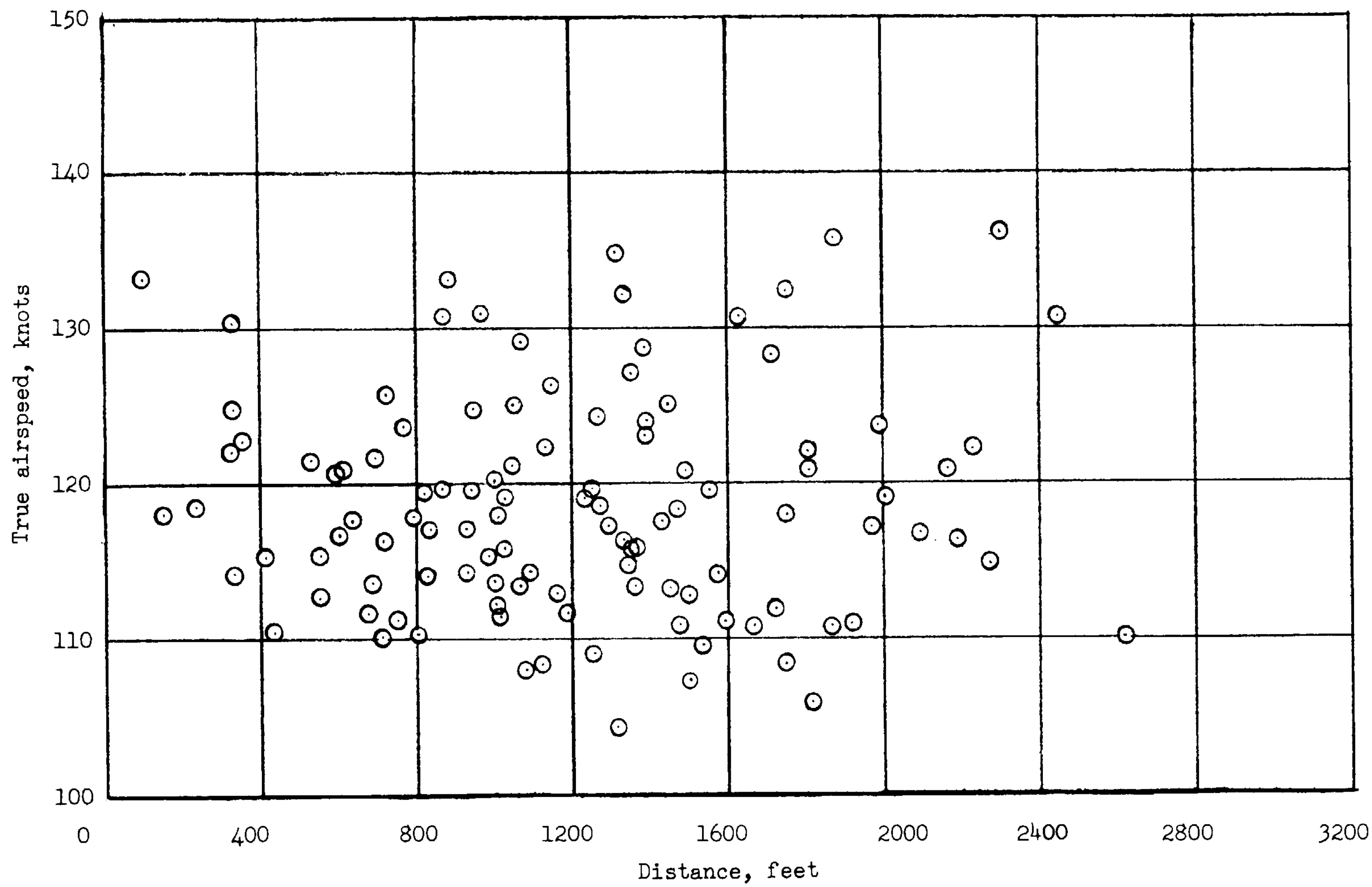
(c) Type IV.

Figure 20.- Concluded.



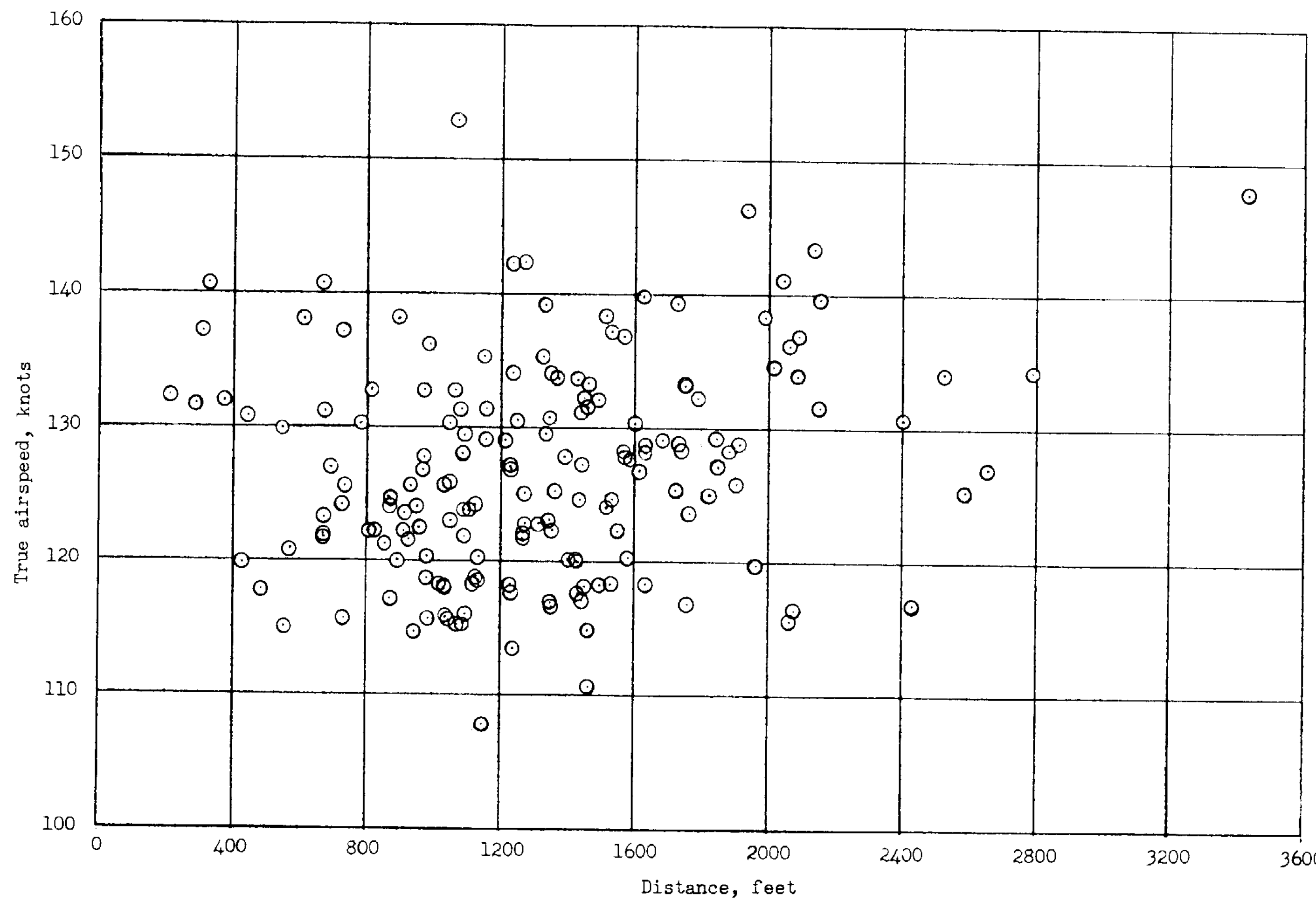
(b) Type II.

Figure 20.- Continued.



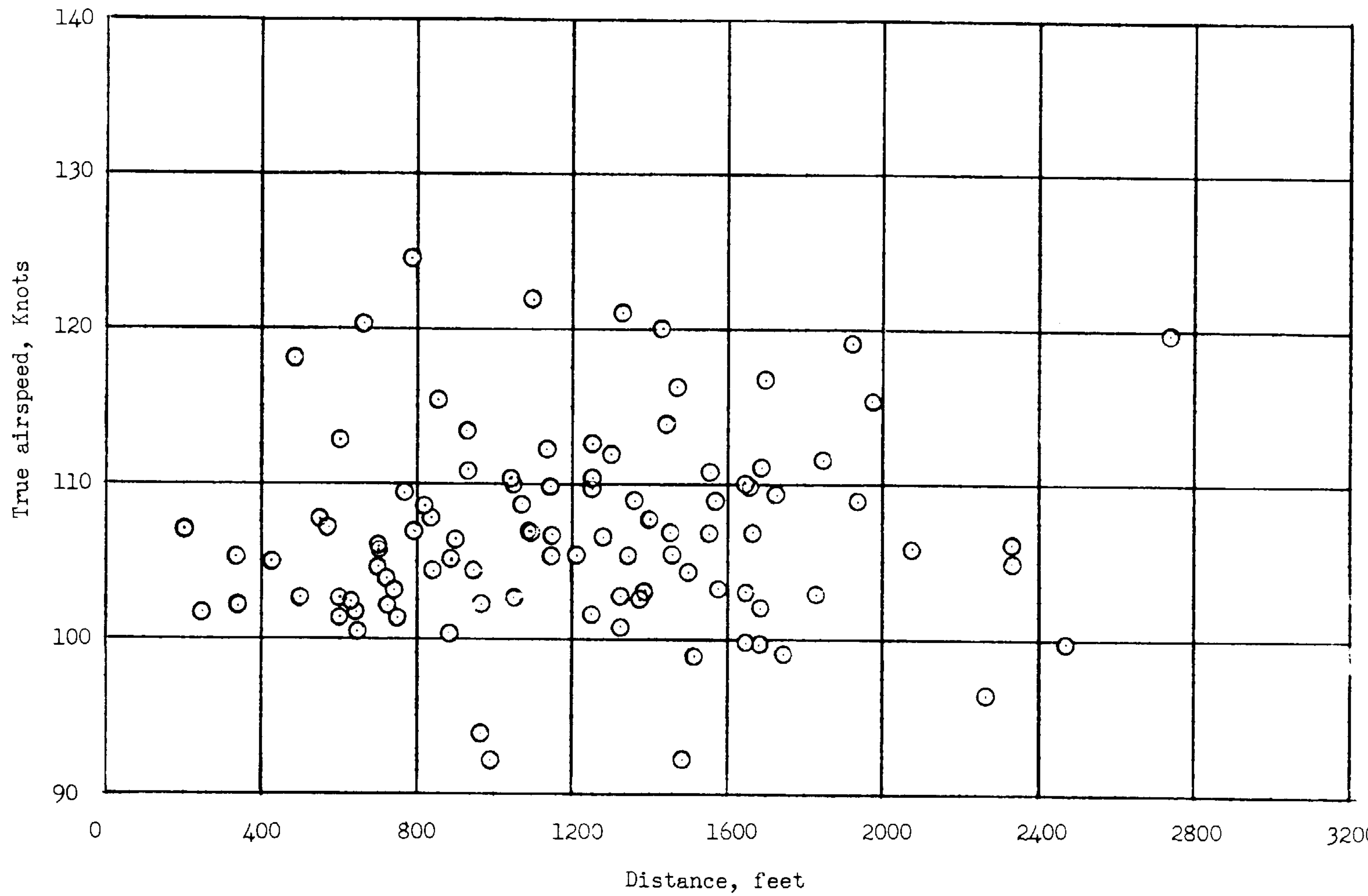
(b) Type II.

Figure 21.- Continued.



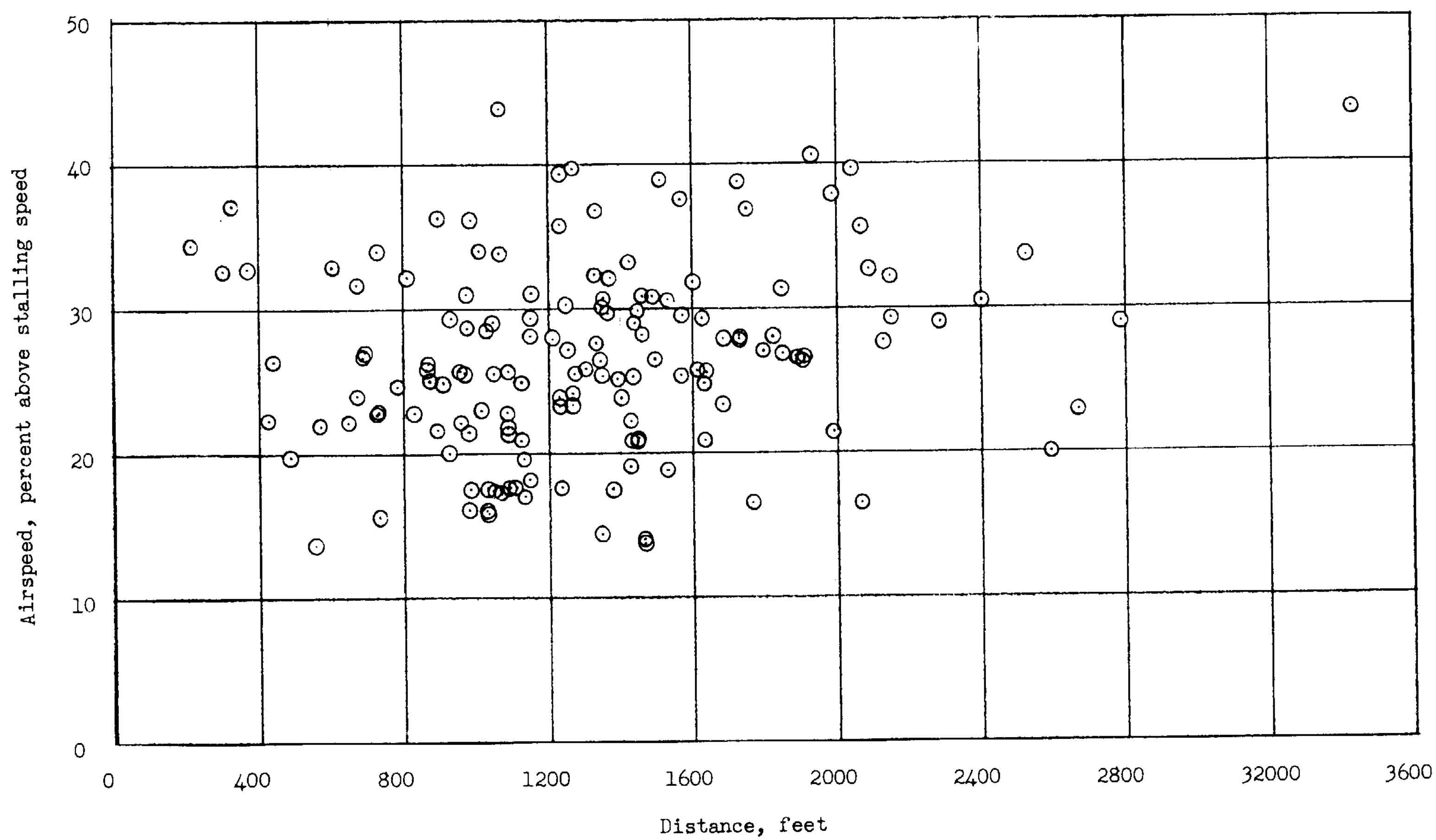
(a) Type I.

Figure 21.- Variation of airspeed with distance from the runway threshold at touchdown for three turbine-powered transports. Camera data.



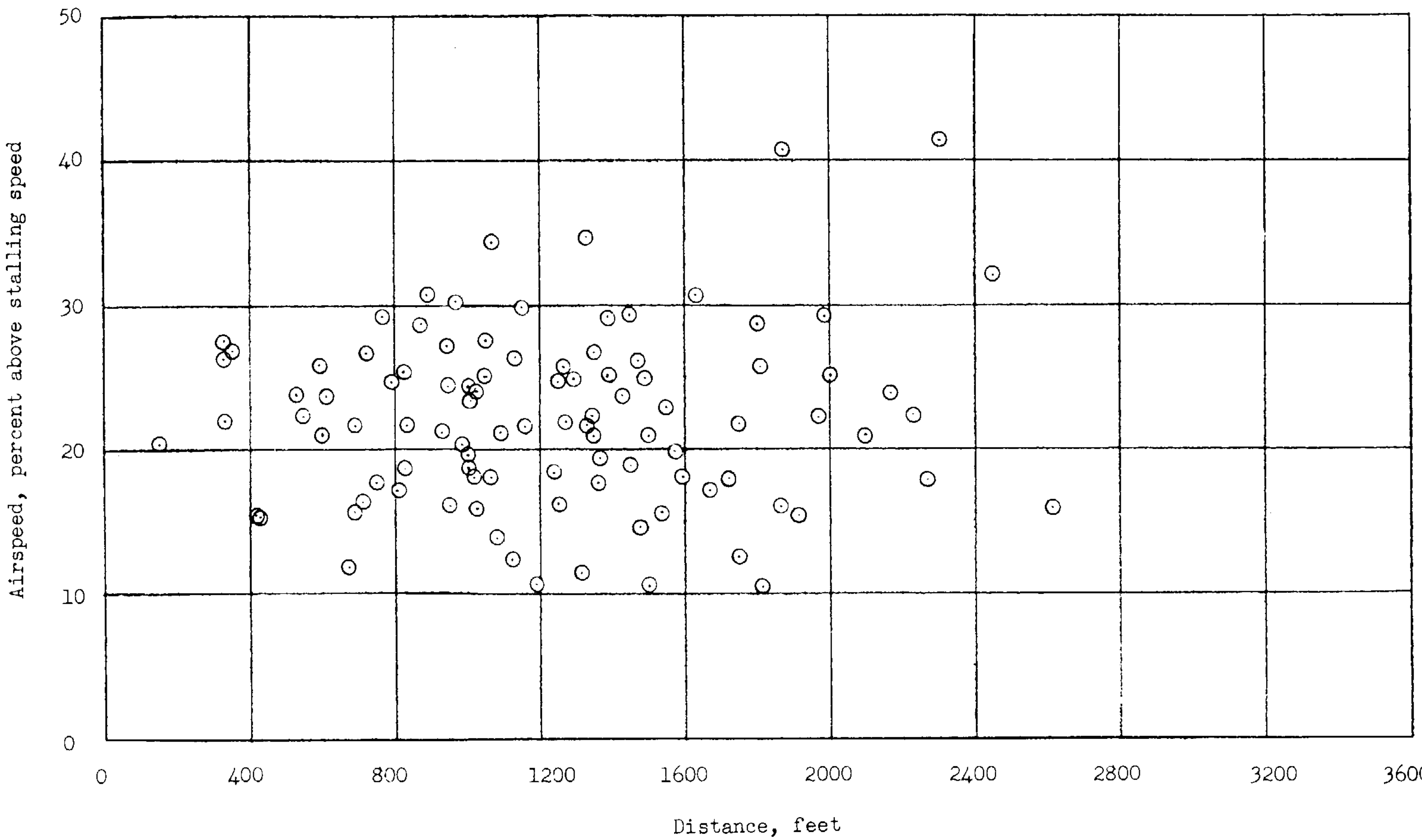
(c) Type IV.

Figure 21.- Concluded.



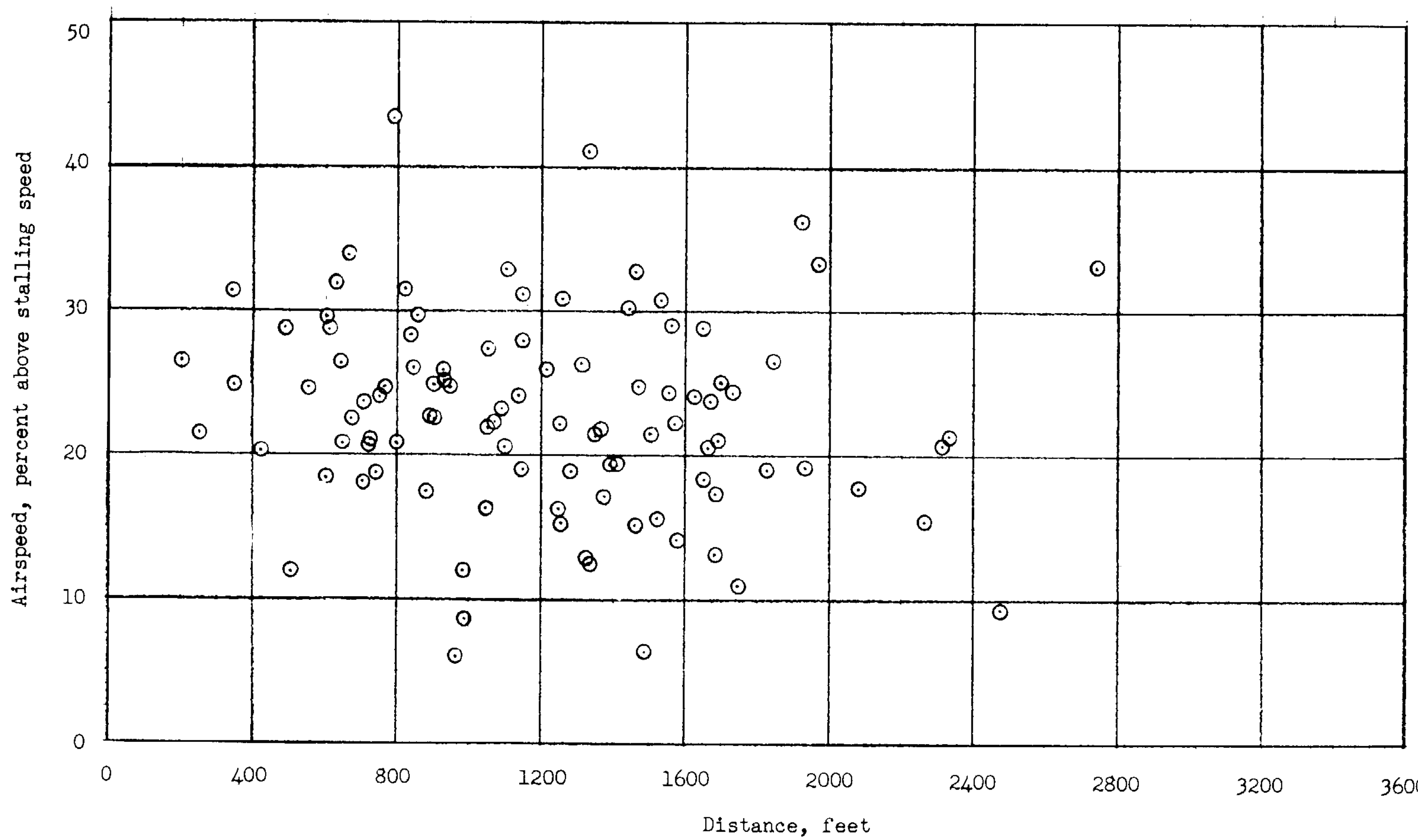
(a) Type I.

Figure 22.- Variation of airspeed in percent above stalling speed with distance from the runway threshold at touchdown for three turbine-powered transports. Camera data.



(b) Type II.

Figure 22.- Continued.



(c) Type IV.

Figure 22.- Concluded.

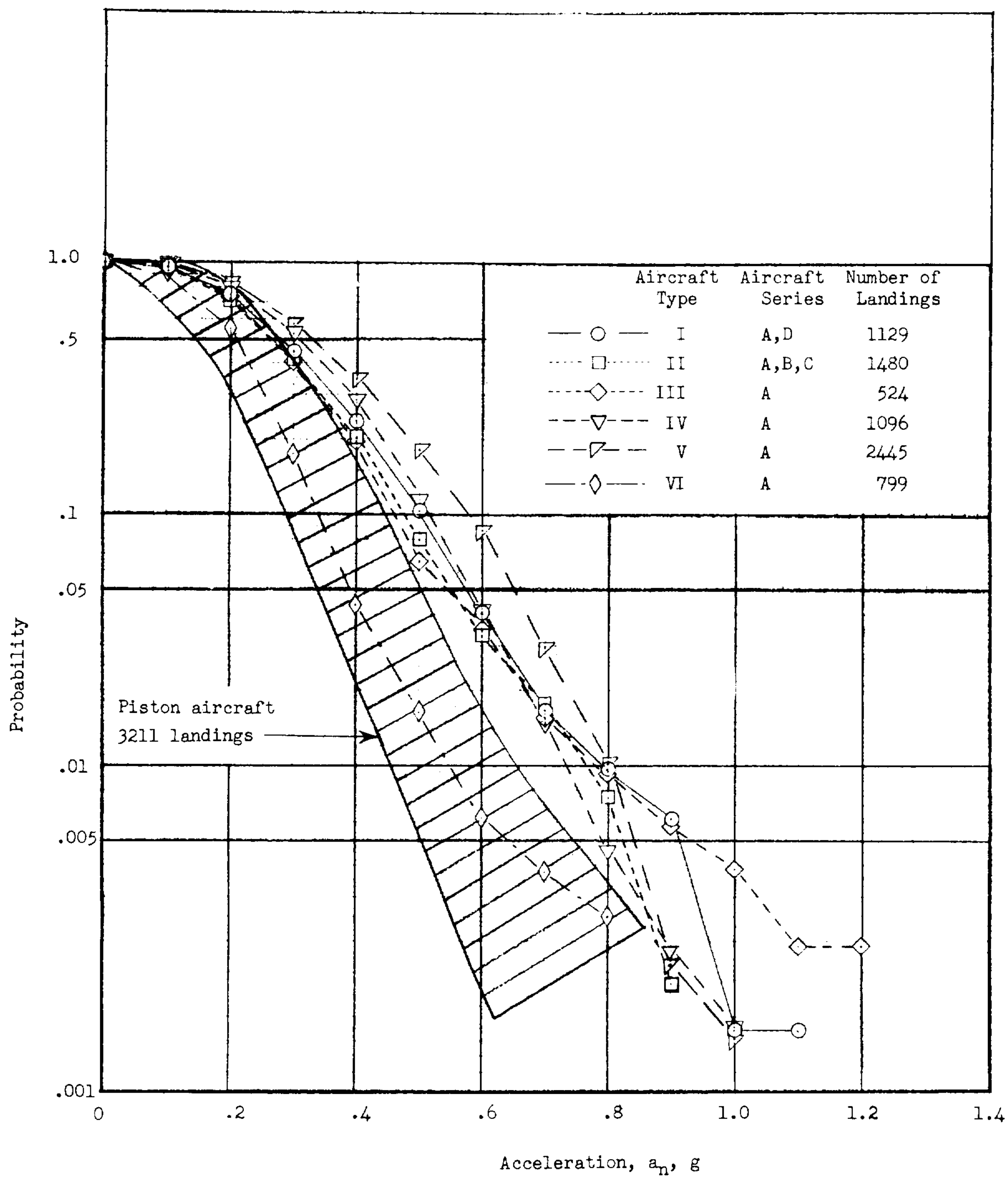


Figure 23.- Comparison of landing-impact incremental accelerations for several types of aircraft. VGH data.

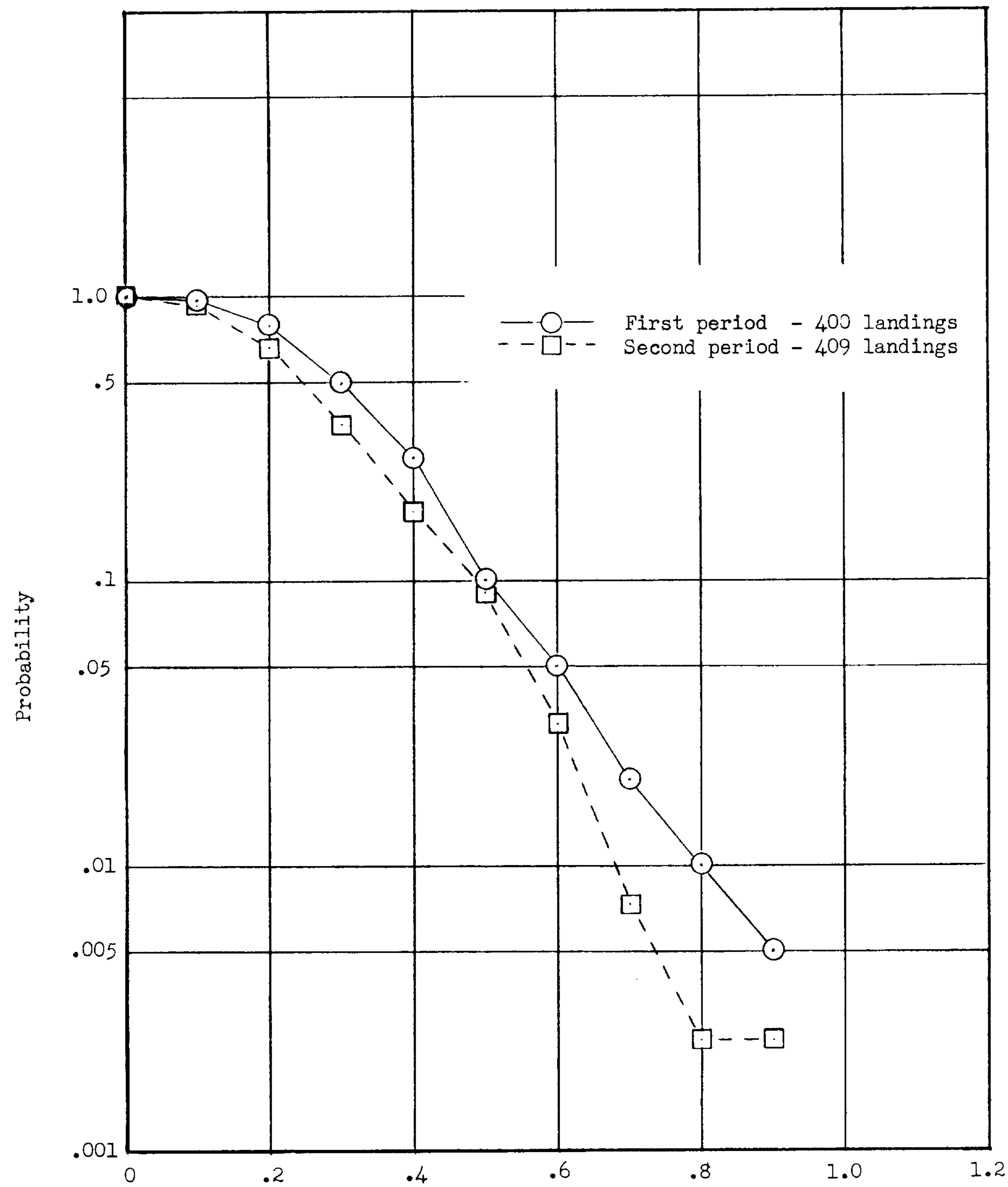


Figure 24.- Effect of pilot experience on landing-impact accelerations. Data from one airplane and one operator. VGH data.

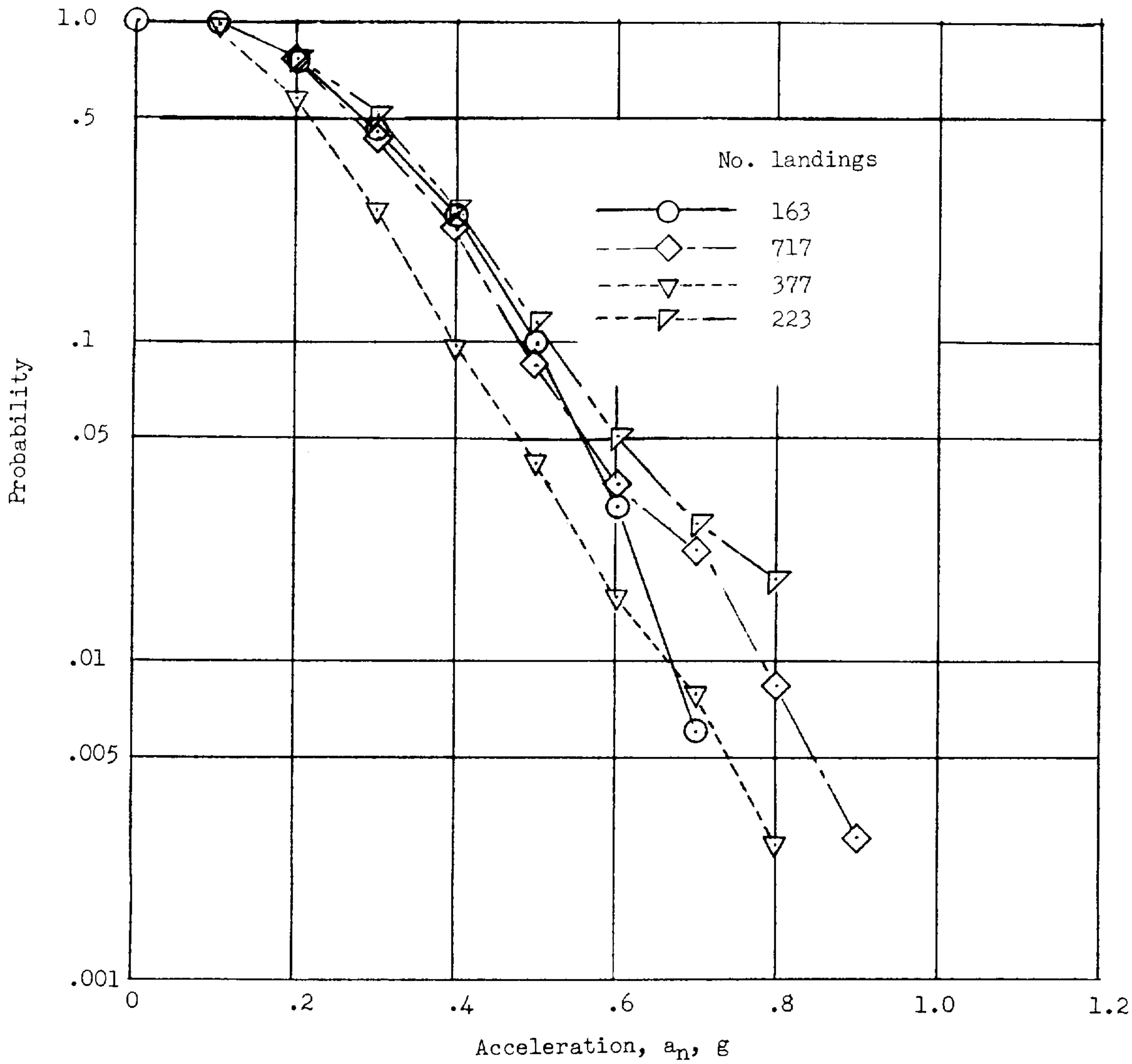


Figure 25.- Landing-impact incremental accelerations experienced by four operators of type II aircraft. VGH data.

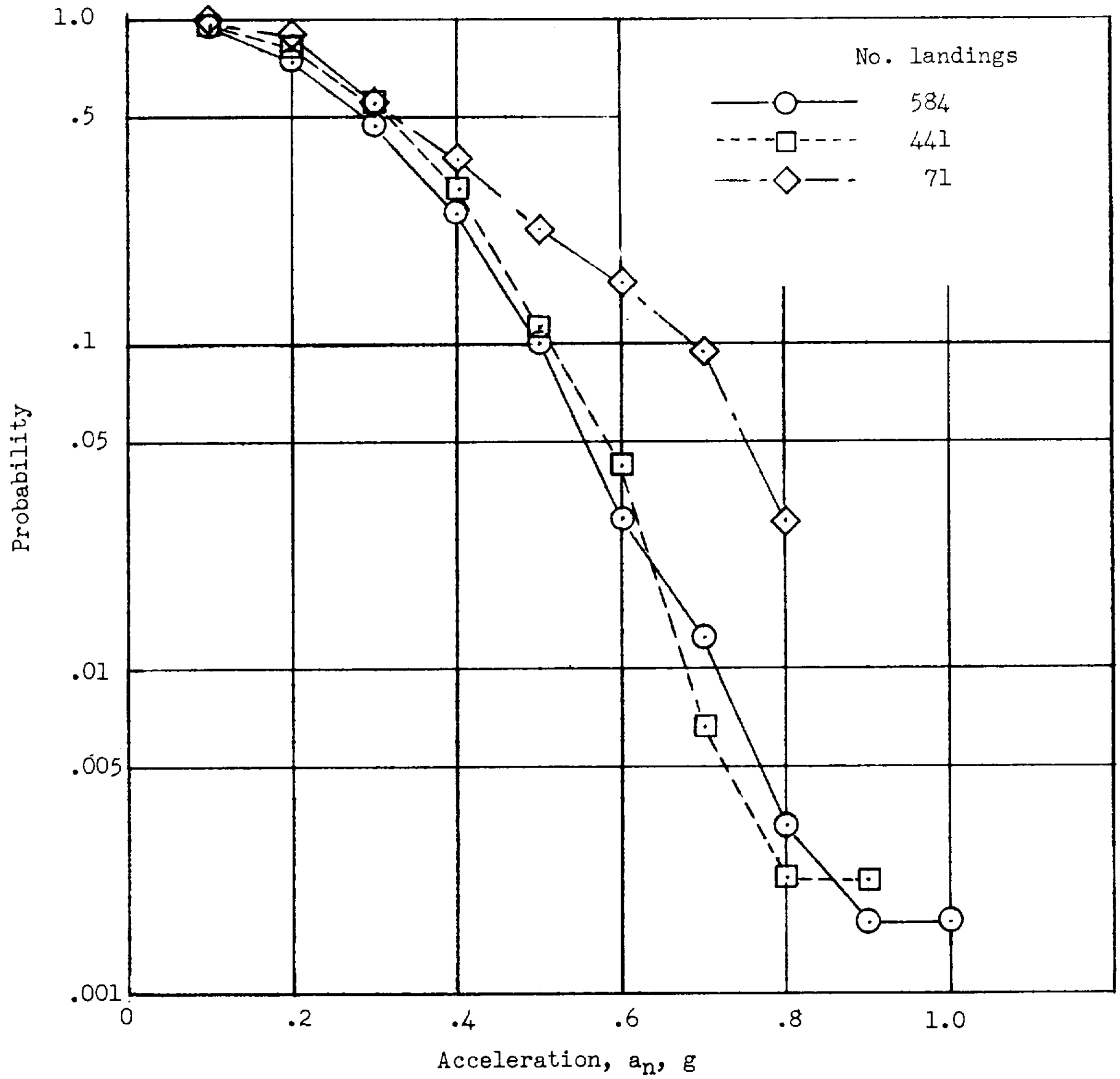


Figure 26.- Landing-impact incremental accelerations experienced by three operators of type IV aircraft. VGH data.

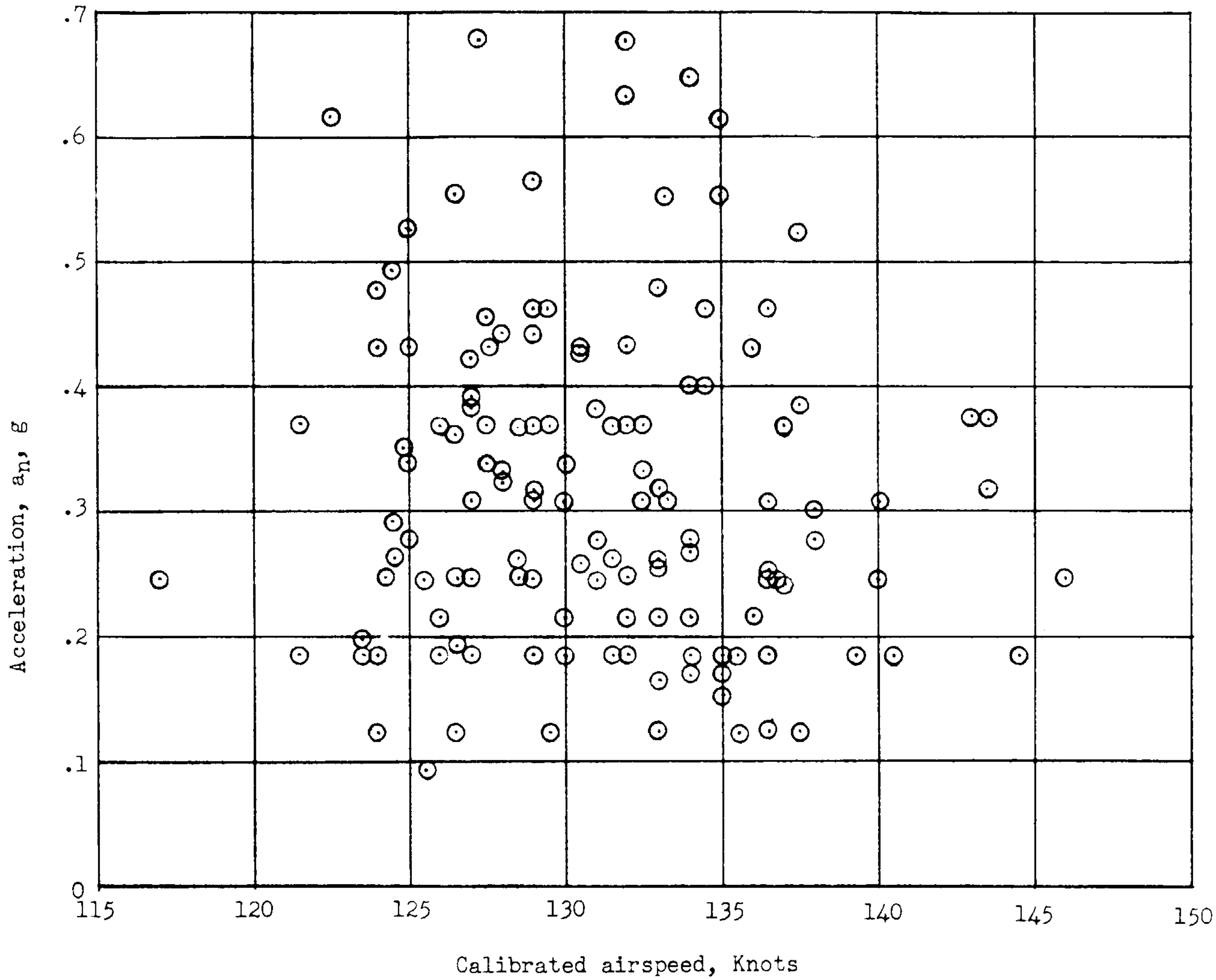


Figure 27.- Variation of landing-impact incremental acceleration with calibrated airspeed at touchdown. VGH data; type I aircraft.

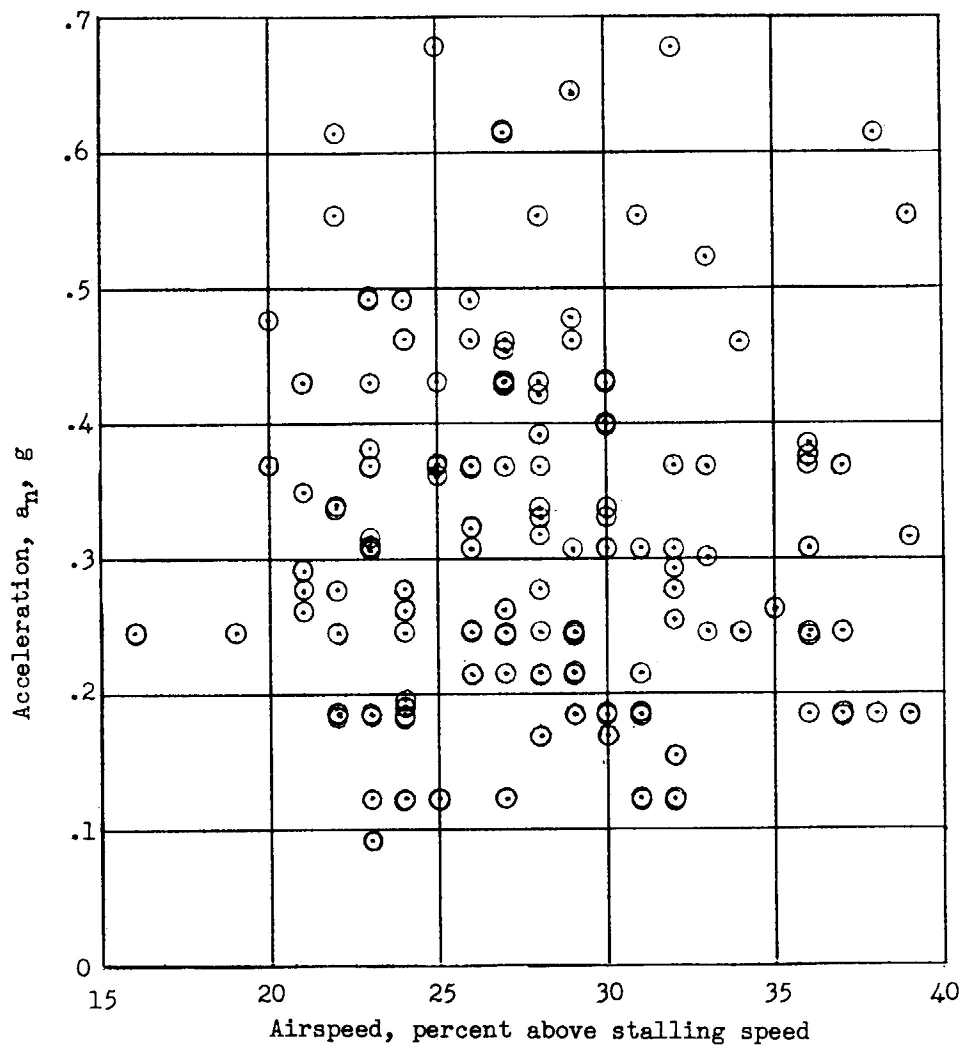


Figure 28.- Variation of landing-impact incremental acceleration with airspeed in percent above stall. VGH data; type I aircraft.

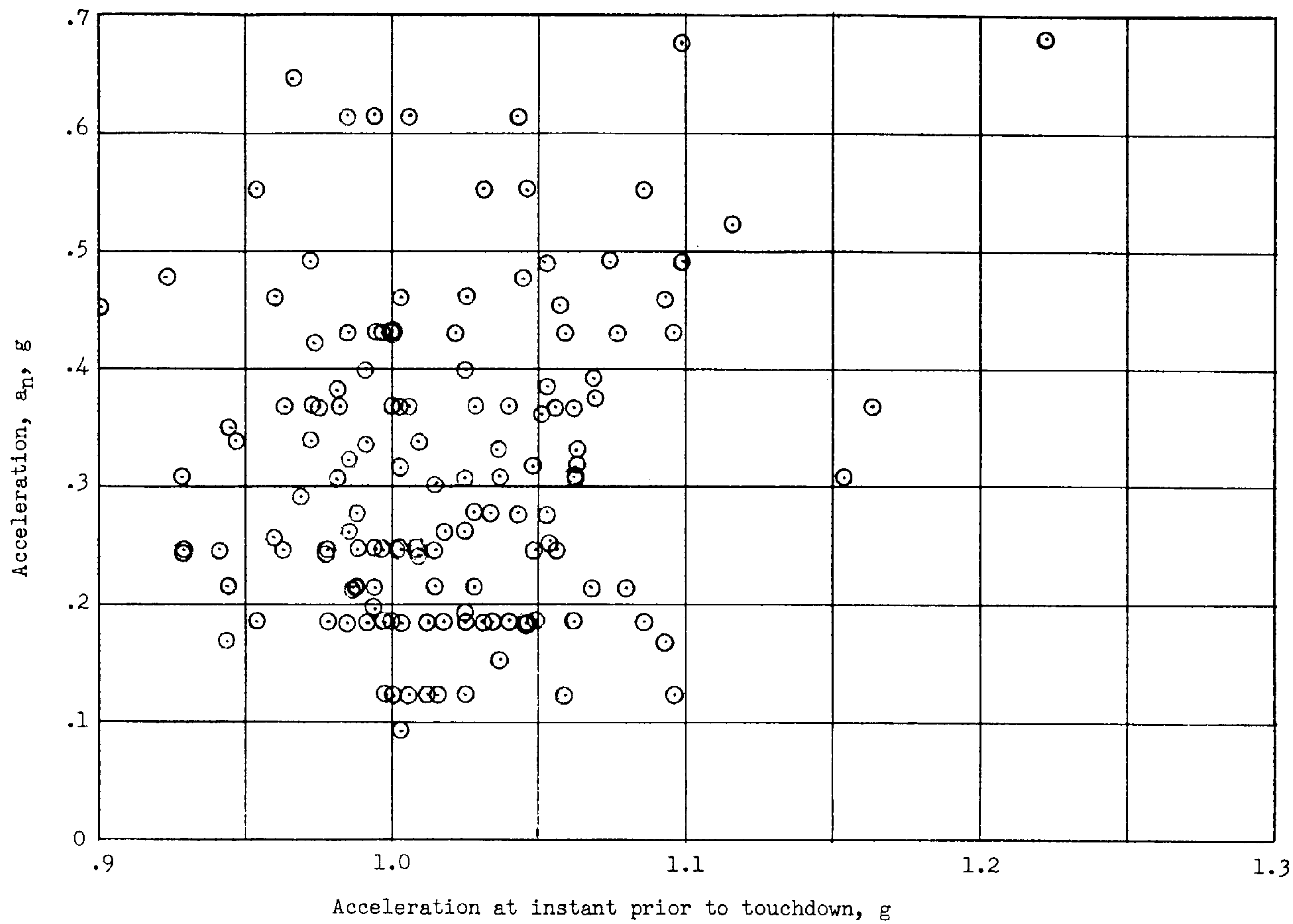


Figure 29.- Variation of landing-impact incremental acceleration with normal acceleration at the instant prior to touchdown. VGH data; type I aircraft.

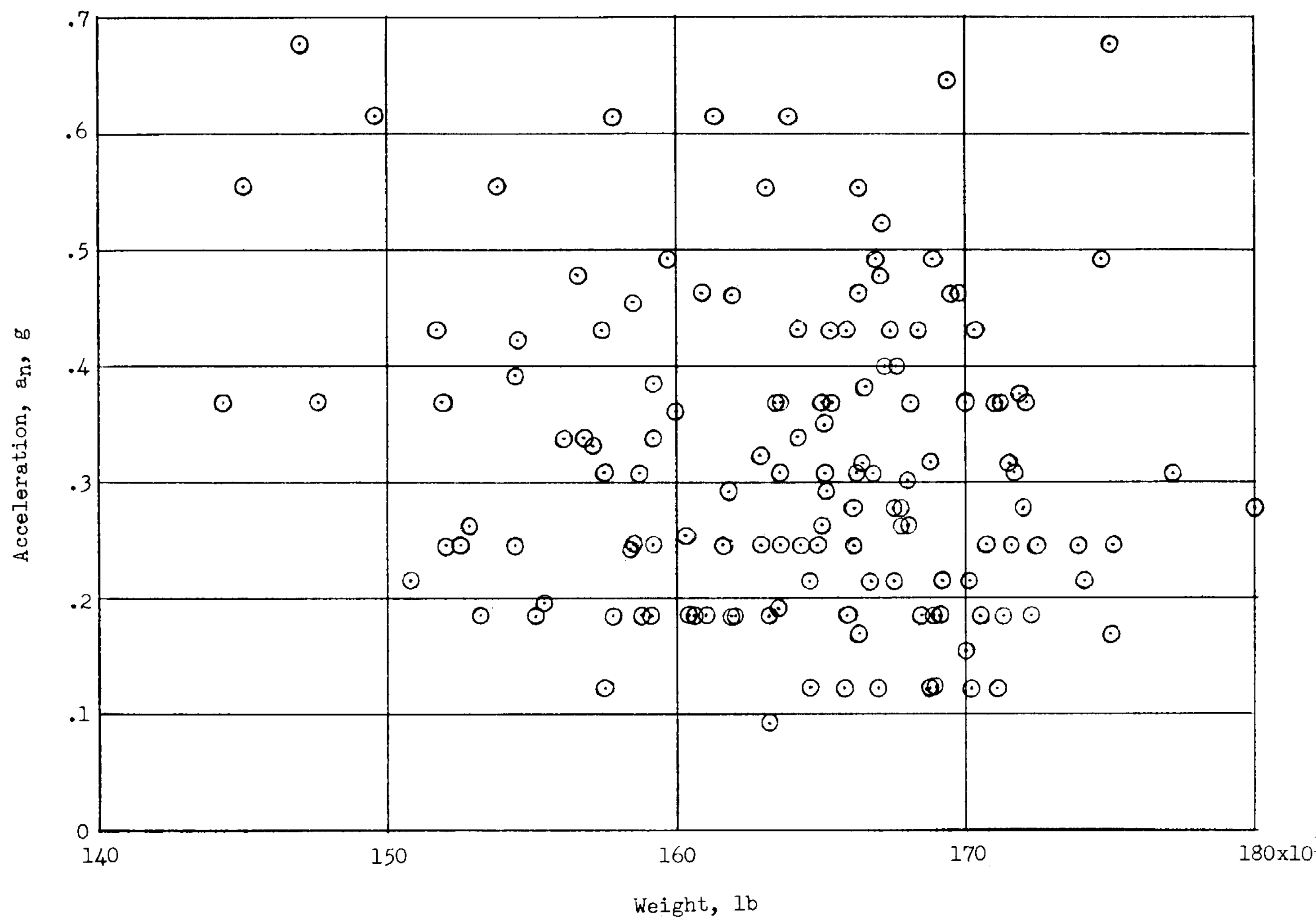


Figure 30.- Variation of landing-impact incremental acceleration with landing gross weight. VGH data; type I aircraft.

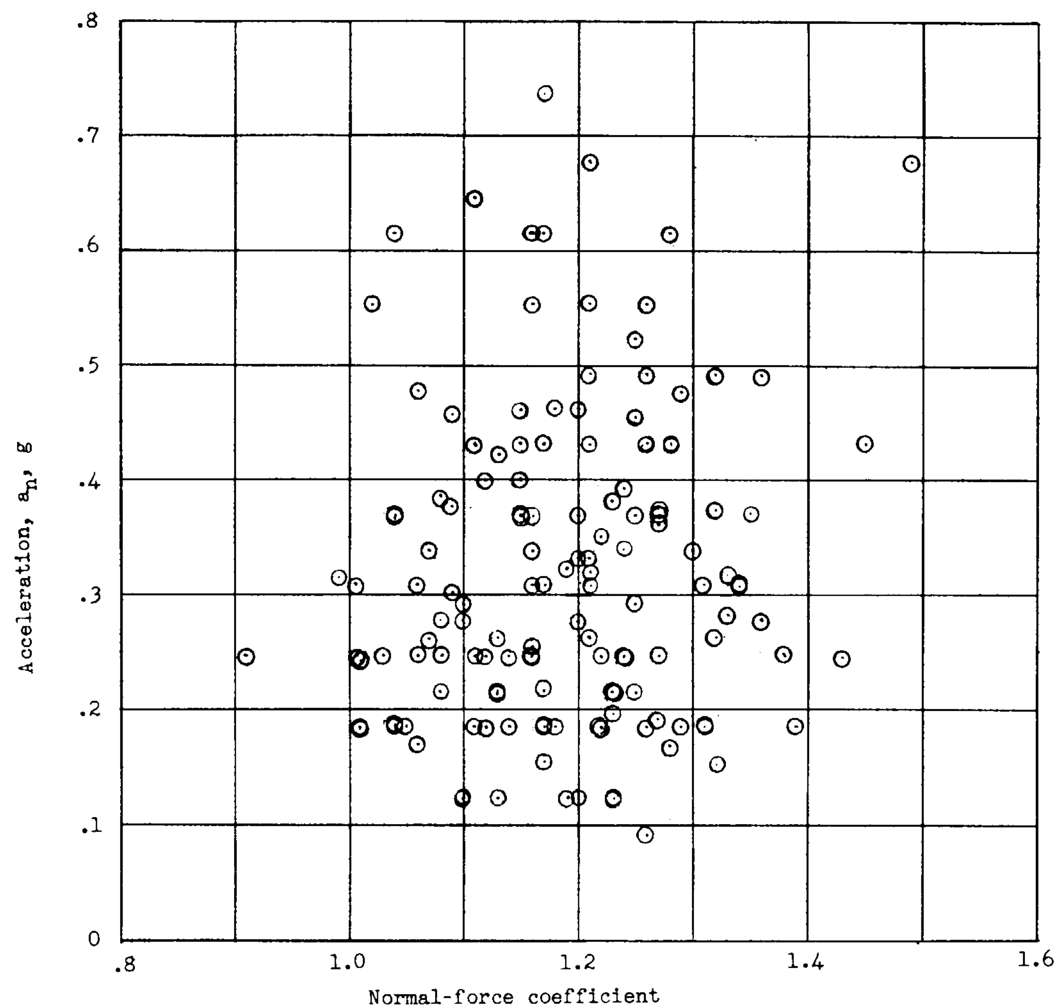


Figure 31.- Variation of landing-impact incremental acceleration with normal-force coefficient. VGH data; type I aircraft.

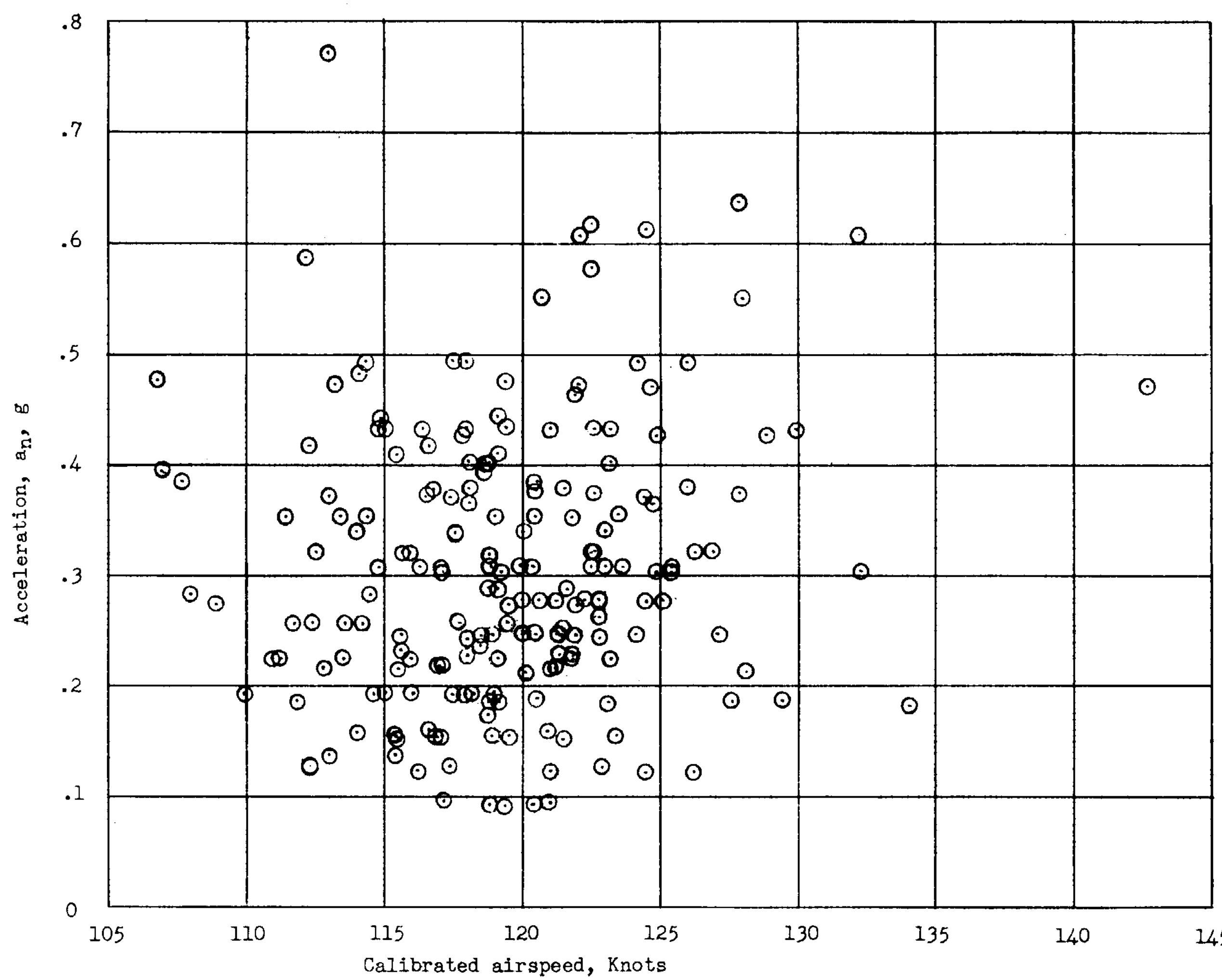


Figure 32.- Variation of landing-impact incremental acceleration with calibrated airspeed at touchdown. VGH data; type II aircraft.

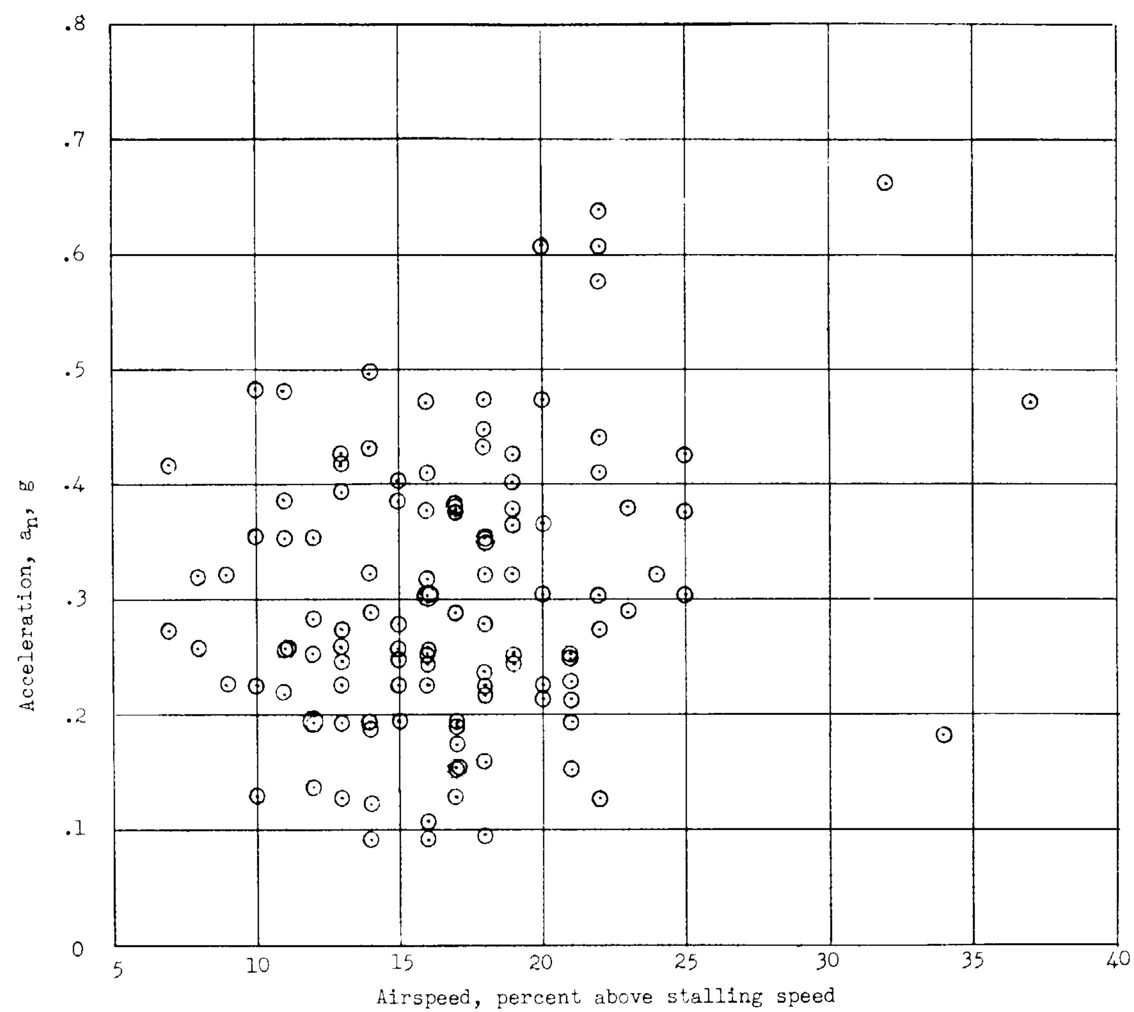


Figure 33.- Variation of landing-impact incremental acceleration with airspeed in percent above stall. VGH data; type II aircraft.

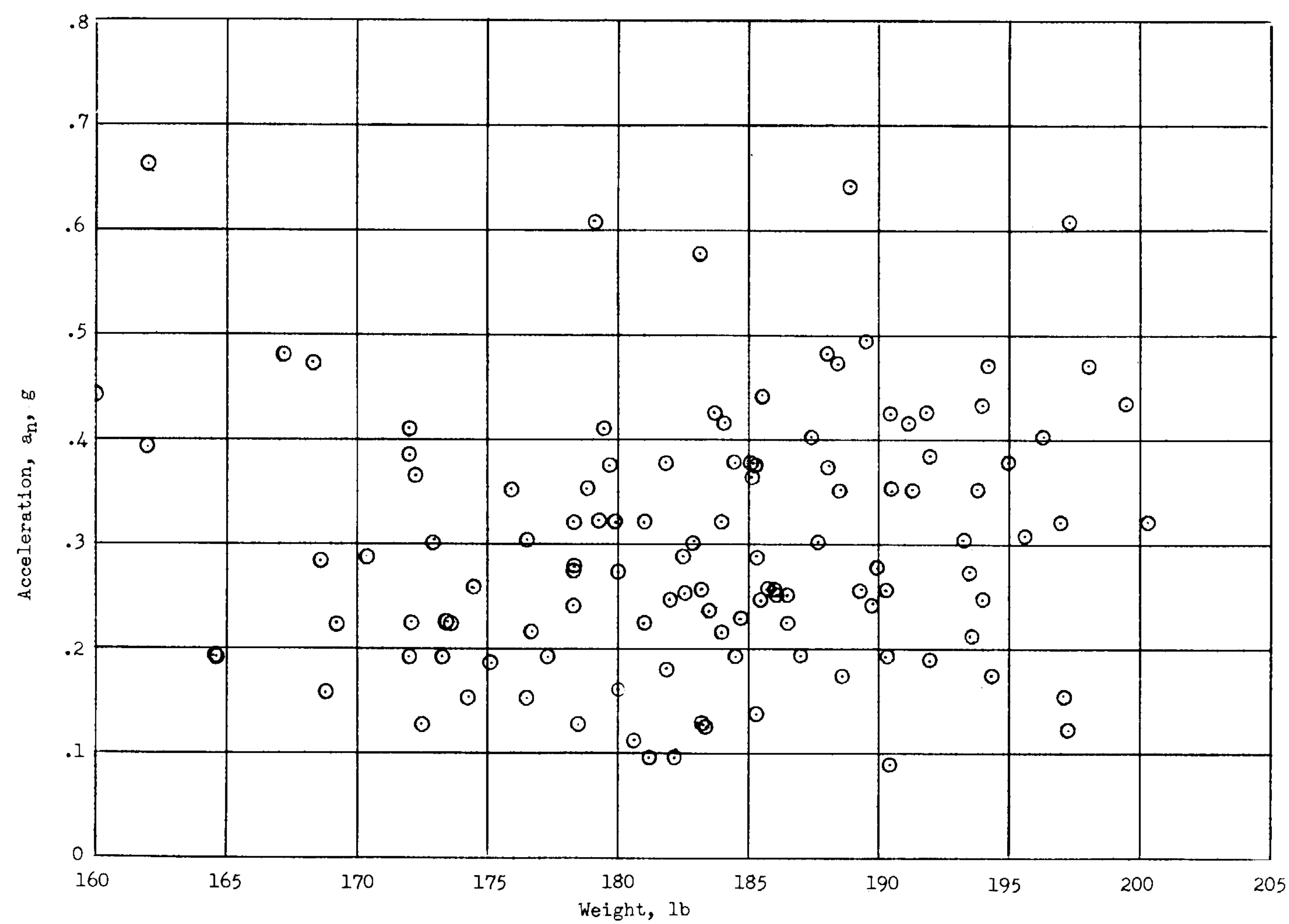


Figure 34.- Variation of landing-impact incremental acceleration with landing gross weight. VGH data; type II aircraft.

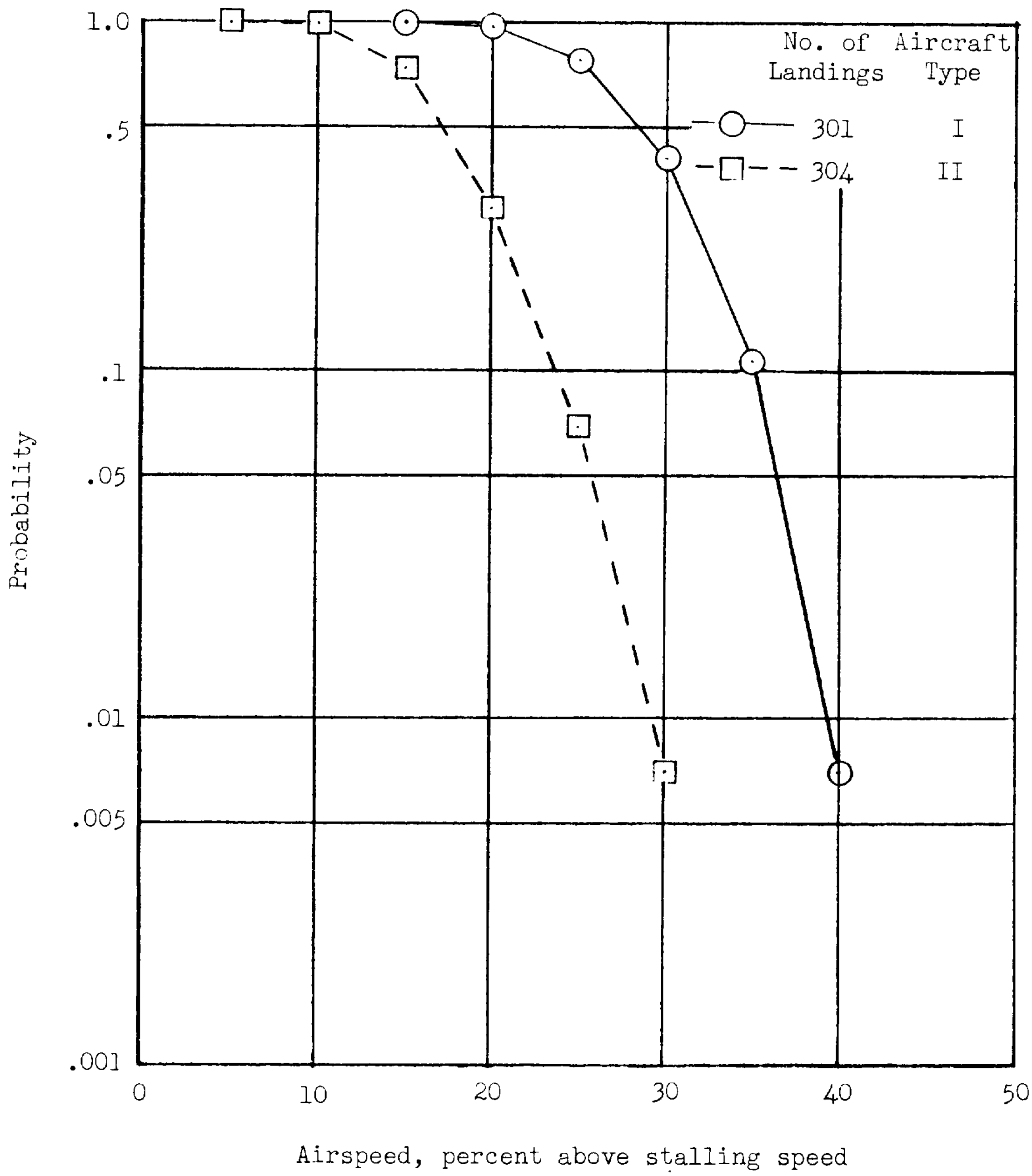


Figure 35.- Probability of equaling or exceeding a given speed at touch-down in percent above stall. VGH data; types I and II aircraft.

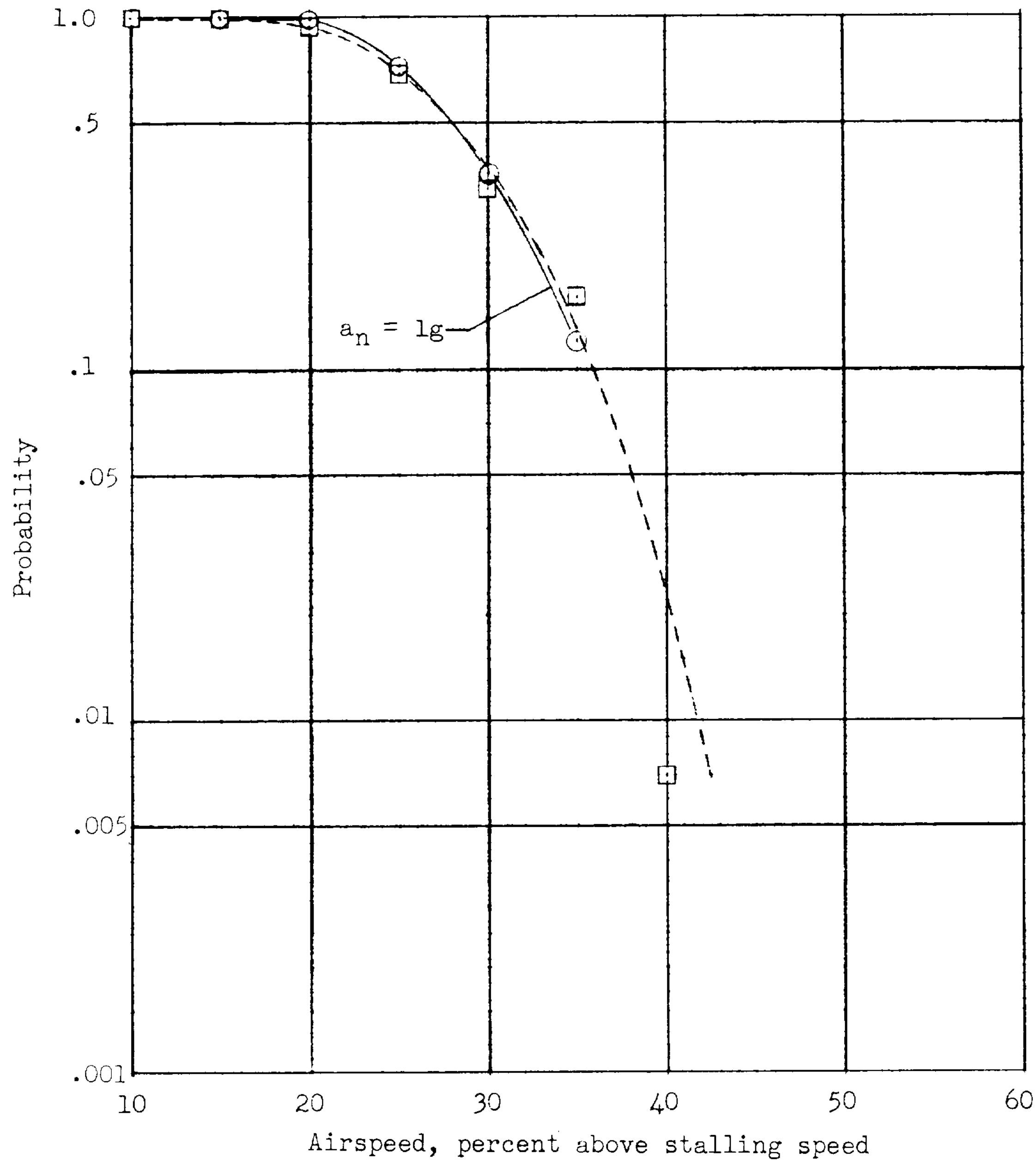


Figure 36.- Comparison of stalling speeds computed by assuming a normal acceleration equal to 1.0g and by using actual measured vertical accelerations immediately prior to touchdown. VGH data.

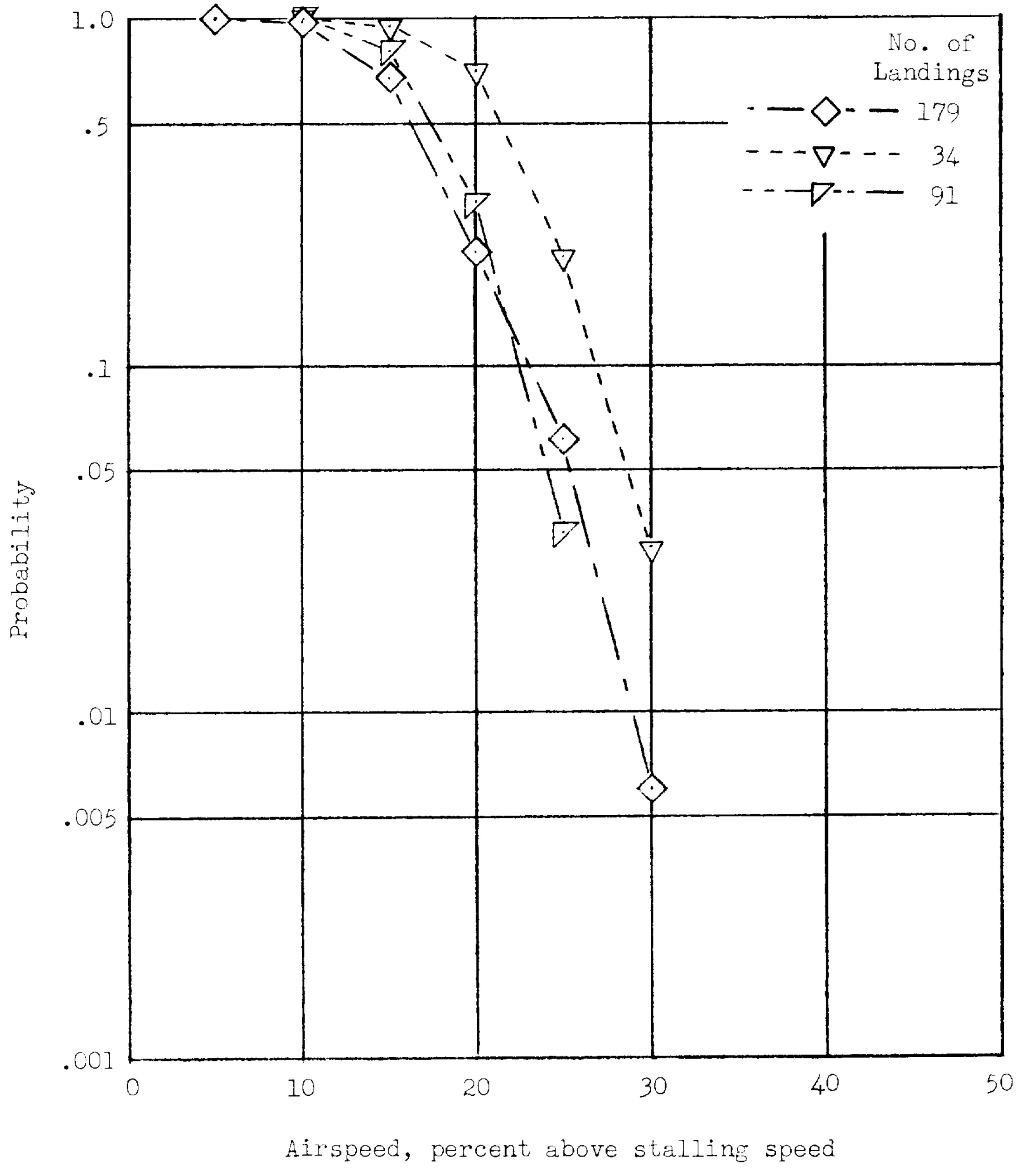


Figure 37.- Landing speed at touchdown in percent above stall for three operators of type II aircraft. VGH data.

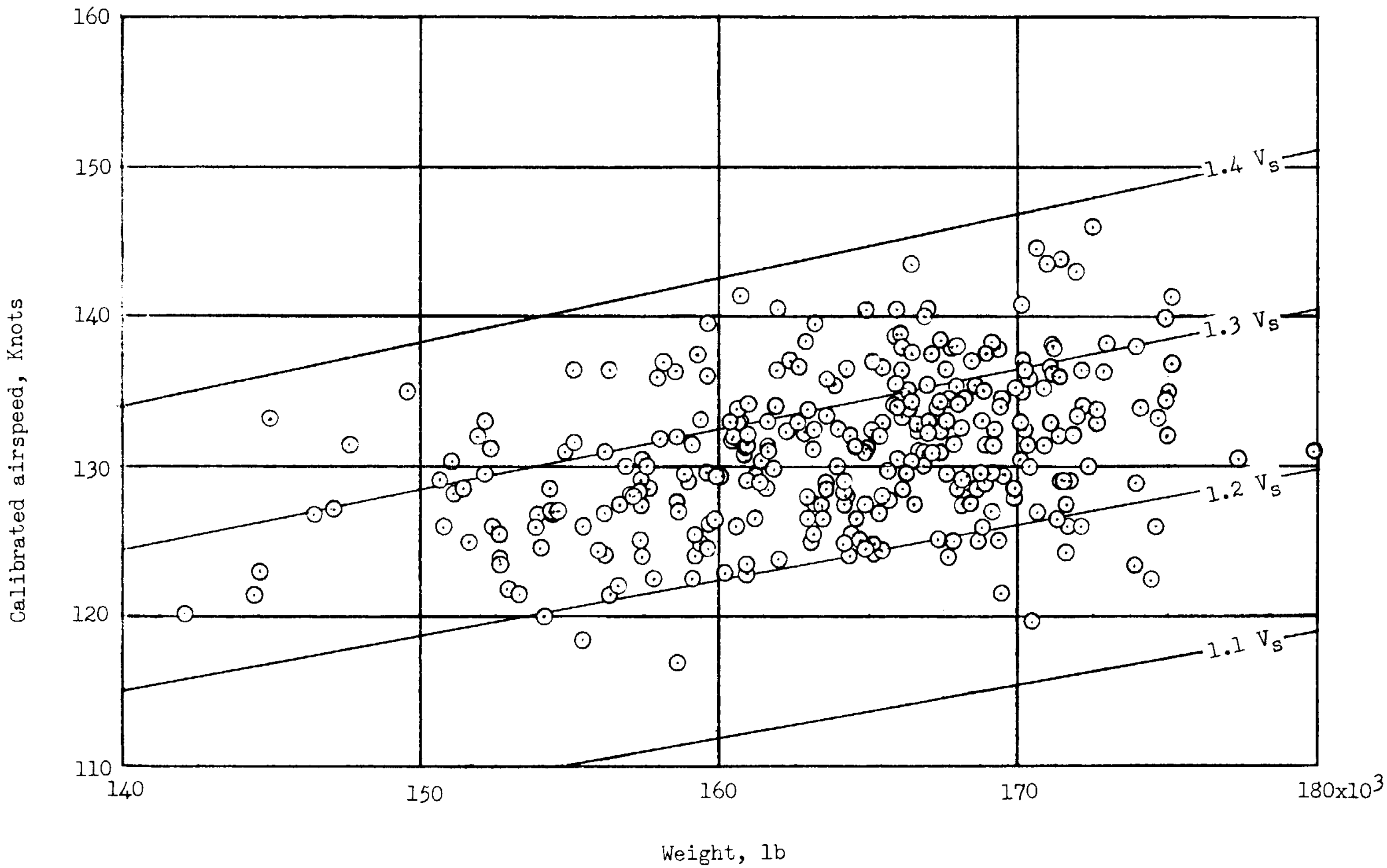


Figure 38.- Variation in touchdown speed with landing weight. VGH data; type I aircraft.

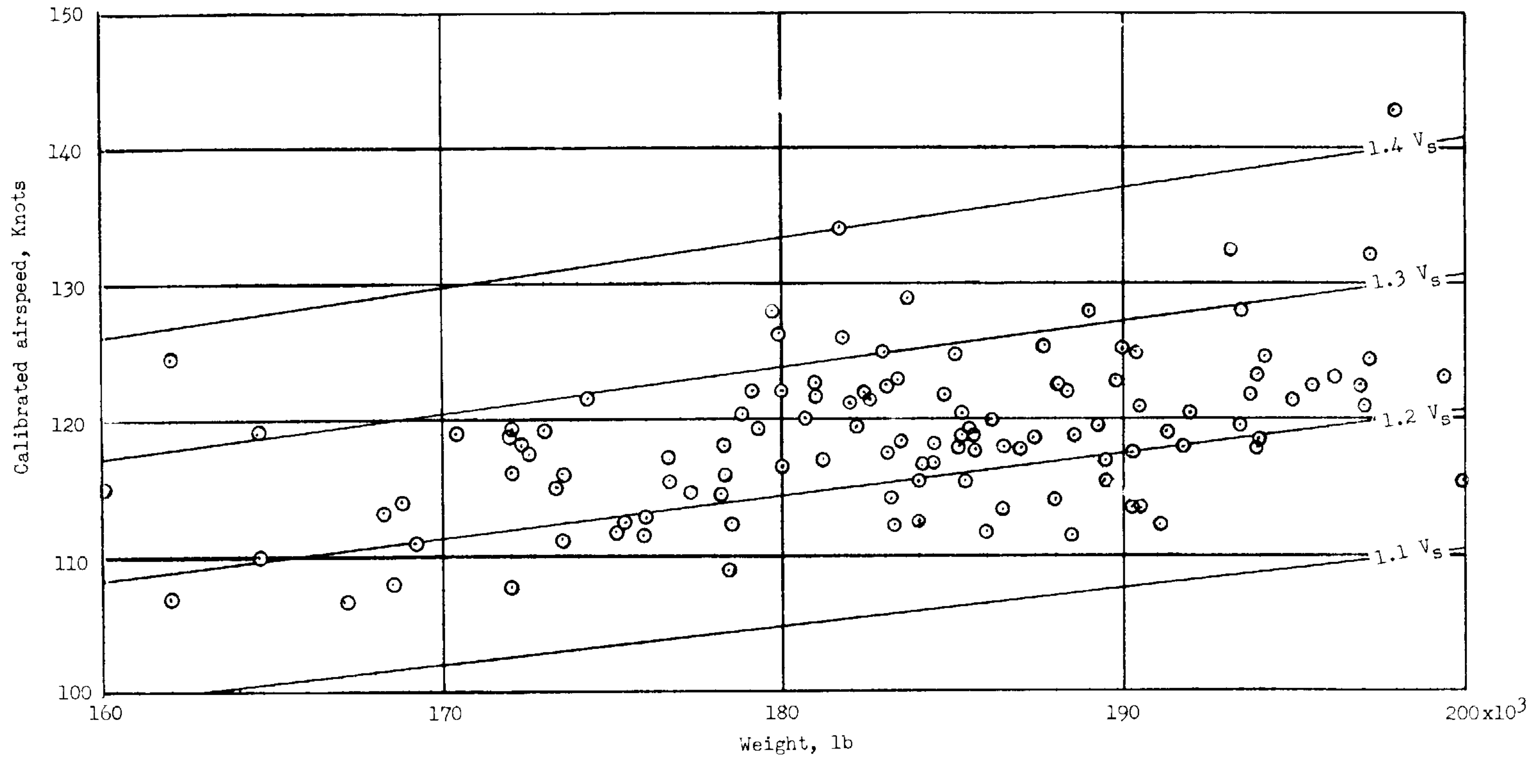


Figure 39.- Variation of touchdown speed with landing weight. VGH data; type II aircraft.

III. COMPARISON OF LANDING-CONTACT CONDITIONS OF COMMERCIAL TURBOJET TRANSPORTS FOR DAY AND NIGHT OPERATIONS

By Joseph J. Kolnick

SUMMARY

VGH data on landing-contact conditions of two types of commercial turbojet transports were analyzed to determine the effect of day and night operations. The results in general showed that the landing-impact accelerations and touchdown airspeeds, both in knots and percent above stall speed, were the same for day and night operations.

INTRODUCTION

Landing-contact conditions of various types of aircraft in routine operations have, in the past, been determined from photographs of the landings taken with a special camera. (See refs. 1 to 3, for example.) Because of the photographic requirements, these measurements had to be made under clear-weather, daytime conditions. Some questions have been raised as to the applicability of the results for design purposes since they did not include nighttime and instrument-flight conditions. Recently some information on landing-contact conditions, such as landing-impact acceleration and touchdown speed, for two types of turbojet transports in commercial operations was obtained from VGH recorders installed in these aircraft. Thus far the data have been sorted into day and night operations, without regard to weather condition. The purpose of this paper is to show the effect of day and night operations on landing-impact accelerations and touchdown speeds.

RESULTS AND DISCUSSION

In sorting the VGH landing data into day and night operations civil twilight time (sun 6° below the horizon) was used as the dividing time. For the data sample available, the time for landings was in all cases sufficiently removed from civil twilight time with the result that the landings could be definitely classed as day or night landings. No distinction was made in the evaluation as to weather conditions. The records evaluated were obtained on types I and II commercial turbojet transports.

The results of the analysis are presented in figures 1 to 3 for type I aircraft and in figures 4 to 6 for type II aircraft. The data are presented in the form of the probability of equaling or exceeding given values of impact acceleration (figs. 1 and 4), airspeed in knots (figs. 2 and 5), and airspeed in percent above stall speed (figs. 3 and 6) for day and night operations.

Comparison of the results in figures 1 to 6 shows that the landing-contact conditions (impact acceleration and landing-contact airspeed) are essentially the same for day and night operations of the two turbojet transports.

CONCLUDING REMARKS

An analysis of VGH data on landing-contact conditions of two types of commercial turbojet transports showed that the landing-impact accelerations and touchdown airspeeds were essentially the same for day and night operations.

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2. Silsby, Norman S., and Livingston, Sadie P.: Statistical Measurements of Contact Conditions of Commercial Transports Landing on Airports at an Altitude of 5,300 Feet and at Sea Level. NASA TN D-147, 1959.

3. Stickle, Joseph W.: An Investigation of Landing-Contact Conditions for Two Large Turbojet Transports and a Turboprop Transport During Routine Daylight Operations. NASA TN D-899, 1961.

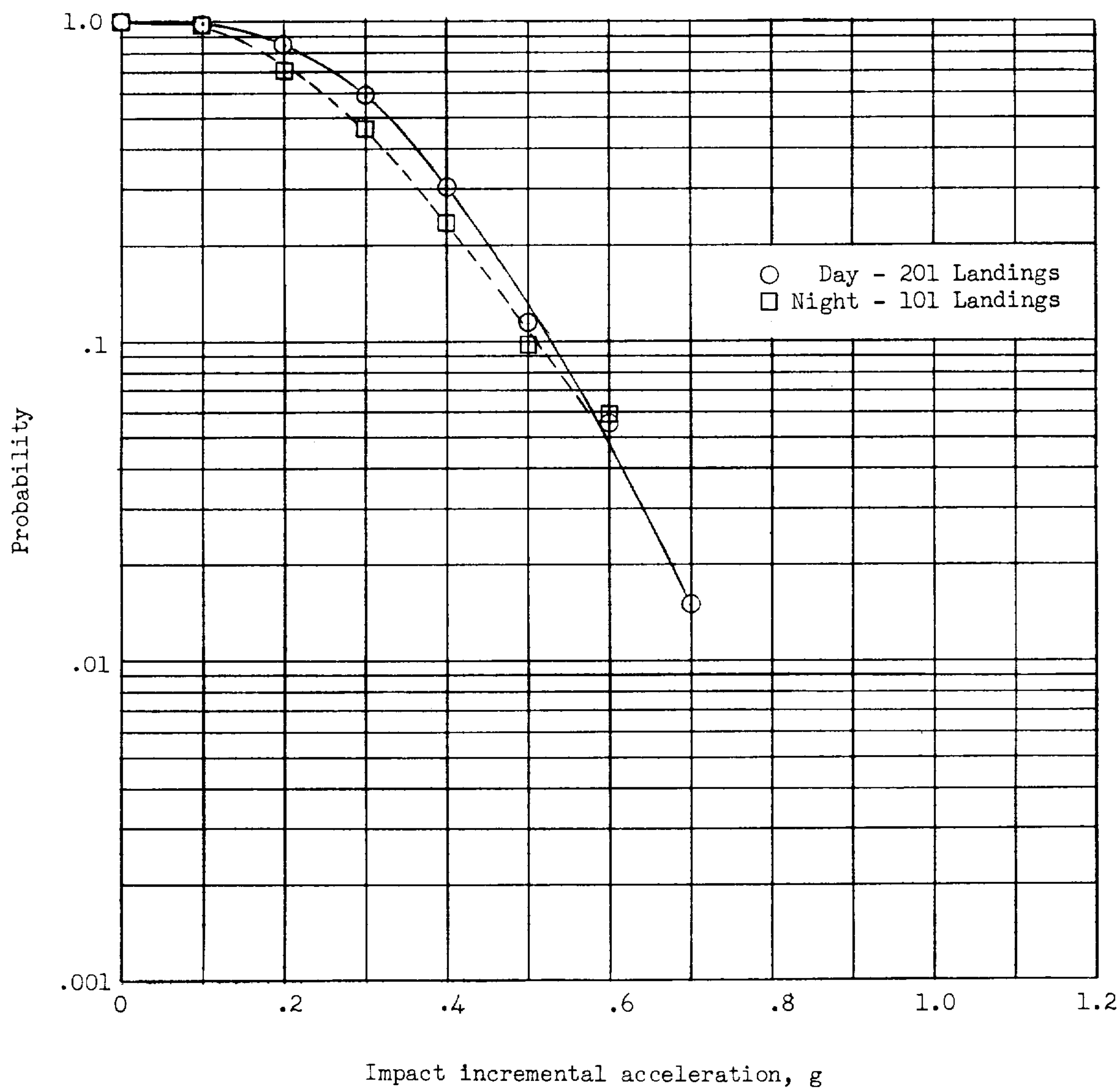


Figure 1.- Probability of equaling or exceeding various impact incremental accelerations for day and night landings of a type I aircraft.

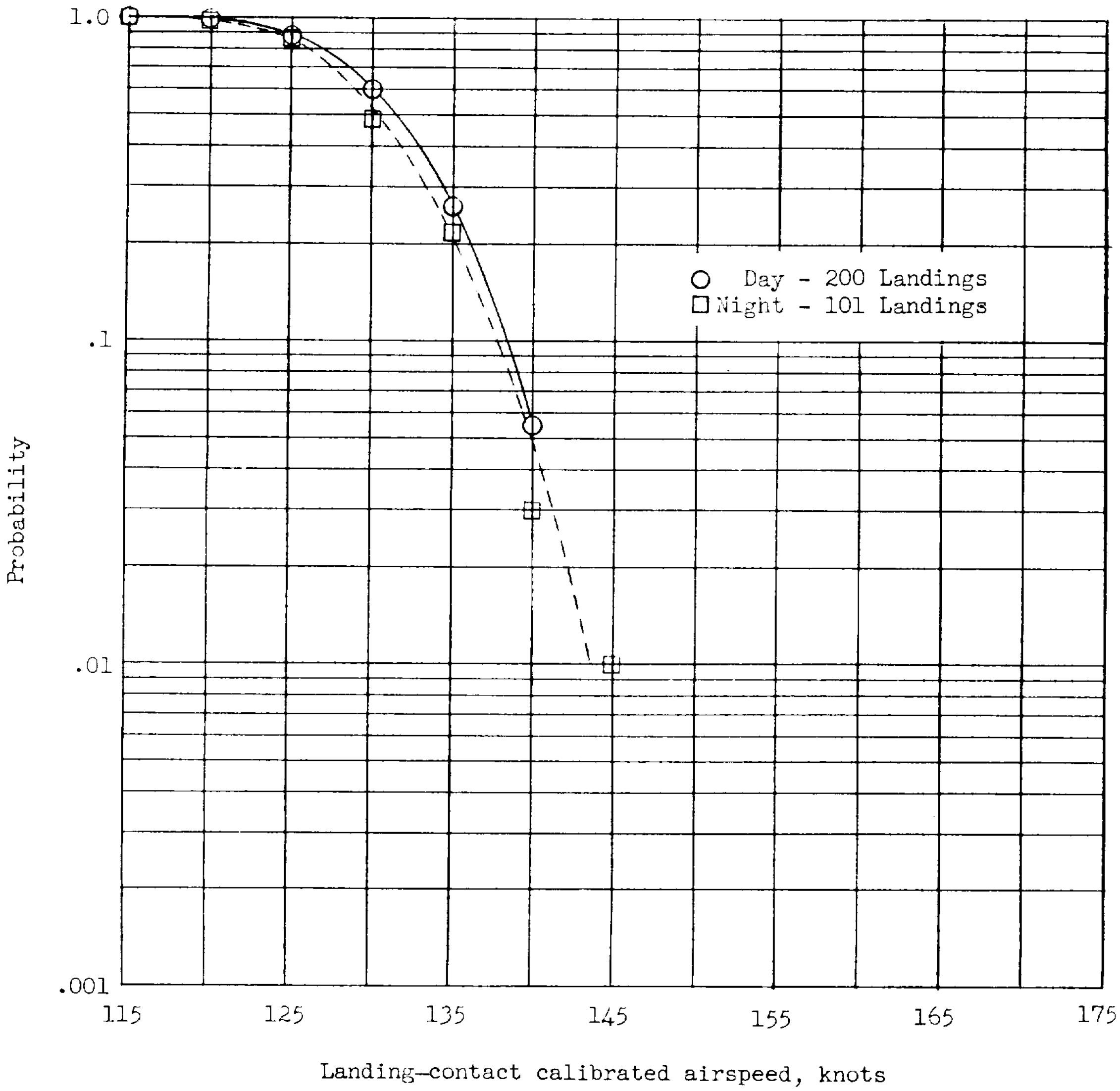


Figure 2.- Probability of equaling or exceeding various airspeeds at landing contact for day and night landings of a type I aircraft.

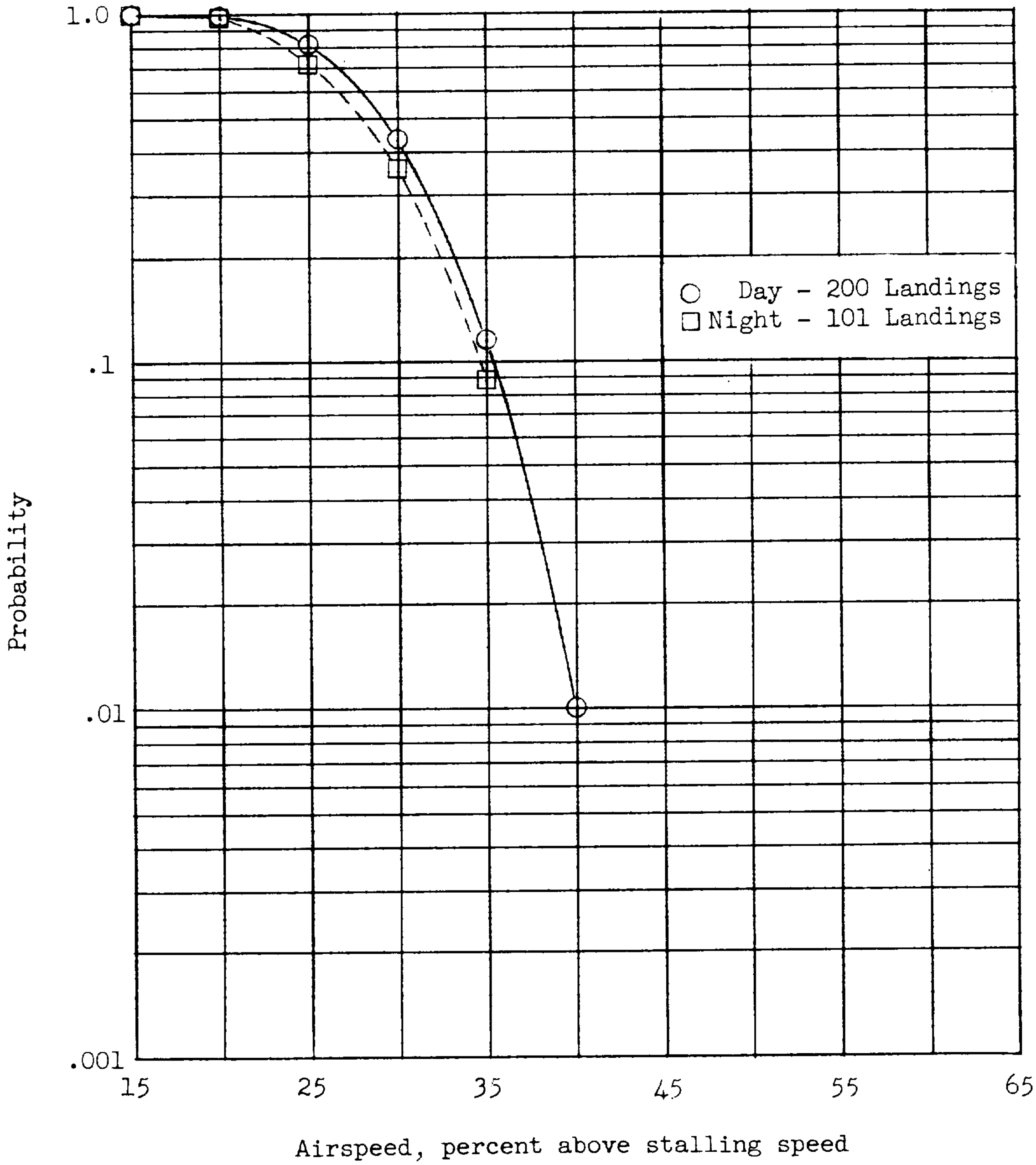


Figure 3.- Probability of equaling or exceeding various airspeeds in percent above stalling speed at landing contact for day and night landings of a type I aircraft.

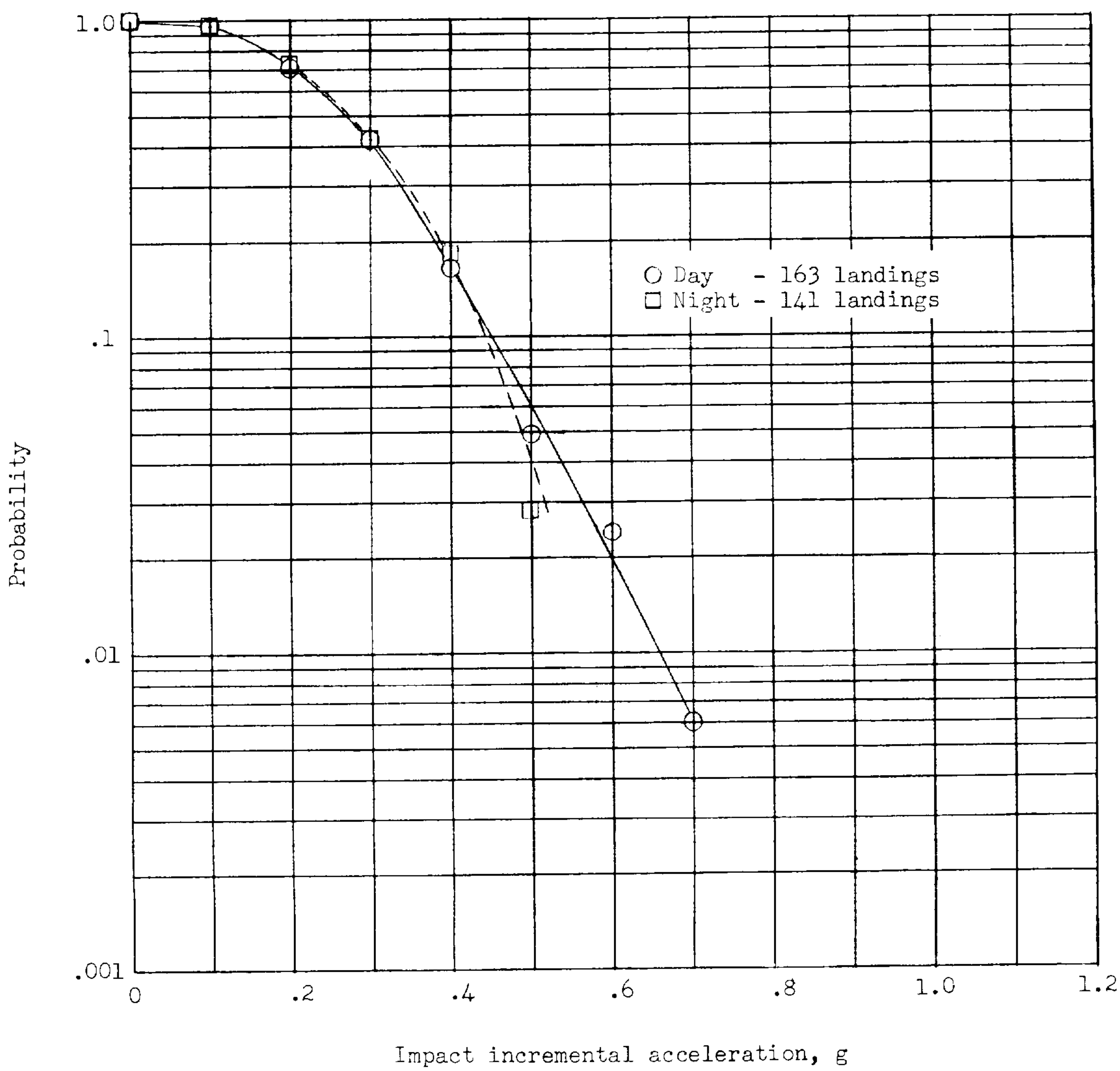


Figure 4.- Probability of equaling or exceeding various impact incremental accelerations for day and night landings of a type II aircraft.

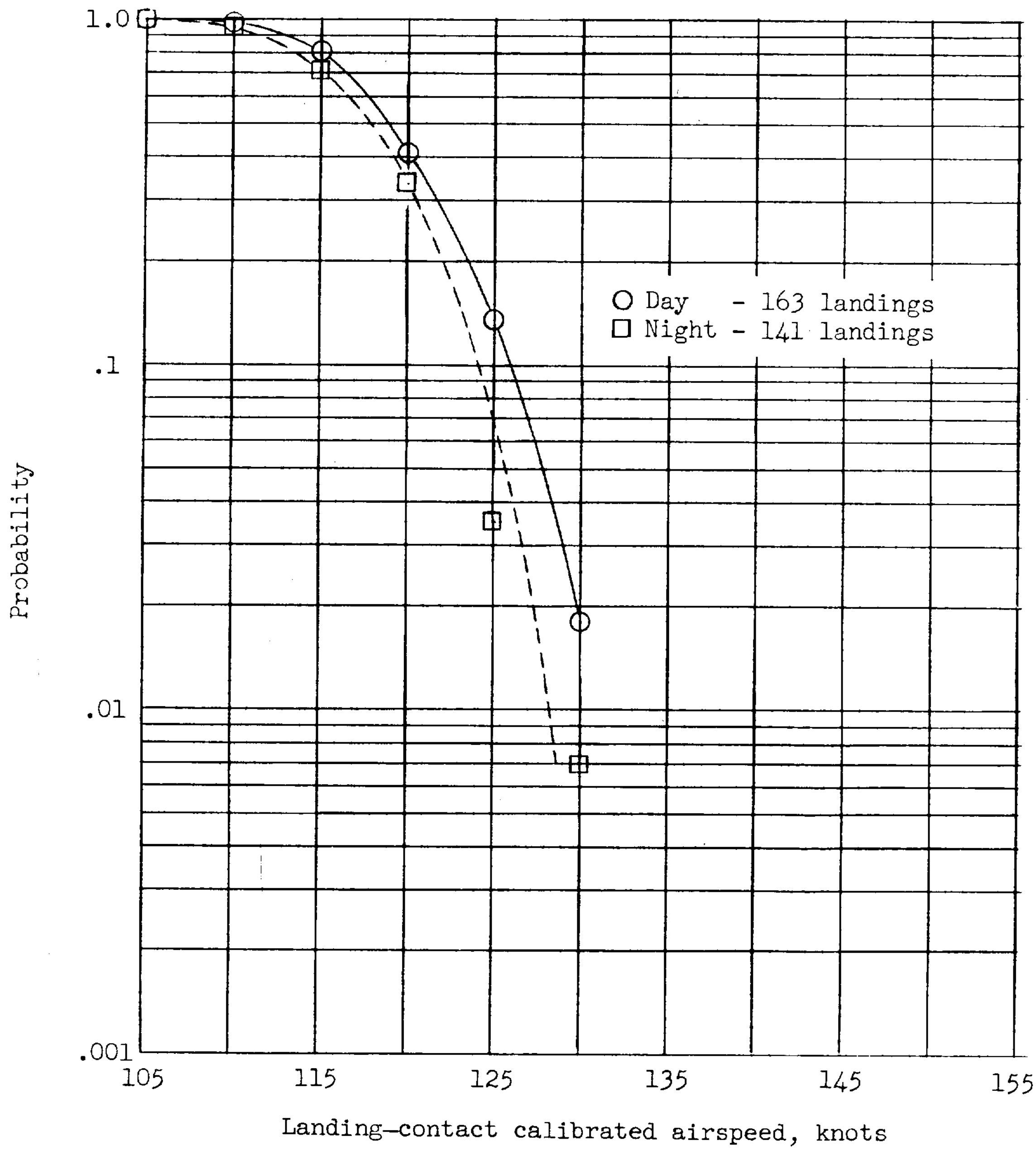


Figure 5.- Probability of equaling or exceeding various airspeeds at landing contact for day and night landings of a type II aircraft.

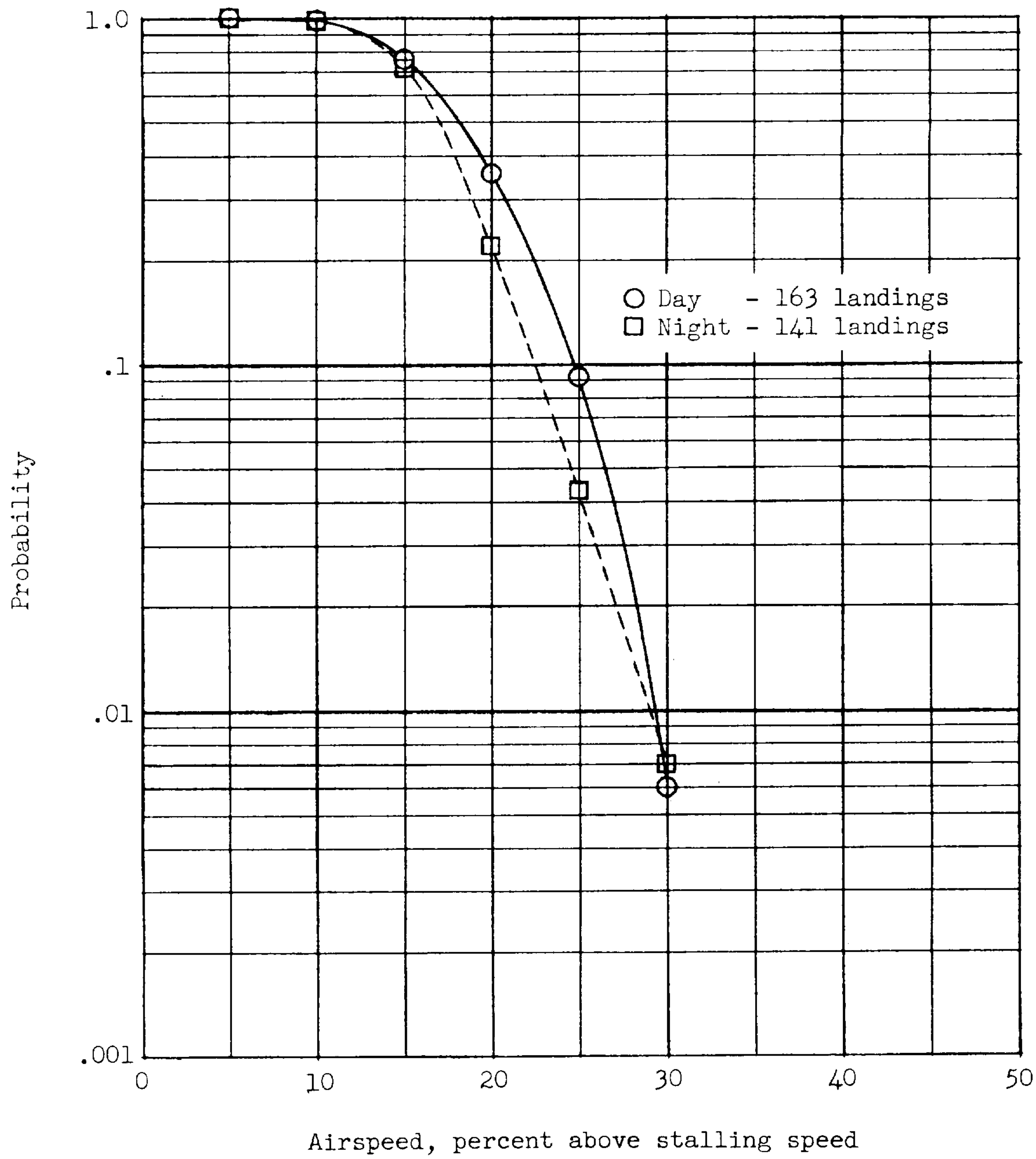


Figure 6.- Probability of equaling or exceeding various airspeeds in percent above stalling speed at landing contact for day and night landings of a type II aircraft.

IV. INFORMATION ON MAXIMUM SPEEDS EXPERIENCED BY TURBINE-POWERED TRANSPORTS

By Paul A. Hunter

SUMMARY

Data obtained with NASA VGH recorders installed on three types of turboprop transports and three types of turbojet transports have been analyzed to determine the relation of the maximum operational speeds to the placard normal-operating and never-exceed speeds. Information is presented on the frequency of exceeding the placard speeds, the magnitudes by which the placards are exceeded, and the flight conditions associated with the exceedances.

INTRODUCTION

Analysis of some of the initial VGH records collected on three types of turboprop transports and one type of turbojet transports (ref. 1) showed that the operational placard speeds were being exceeded significantly more frequently than had been experienced in operations of piston-engine transports. These overspeeds were cause for concern inasmuch as the concepts under which the airplanes were designed did not envisage frequent operations at speeds in excess of the operational placards. In view of this situation, considerable attention was given to the overspeed problem during 1960 and 1961. The prevalence of overspeeding was discussed by NASA personnel with most of the operators of turbine transports and also was discussed among various segments of the aviation industry at the Federal Aviation Agency's Airworthiness Conference held in Washington, D.C., March 1960. These discussions have culminated in revisions (see FAA Regulation No. SR-450) to the Civil Air Regulations pertaining to operational speed placards and overspeed warning devices.

Since the reporting of the initial overspeed data in reference 1, additional data concerning the overspeeds have been obtained from VGH records. These data cover operations for two 3-month periods: July to September 1960, and December 1960 to February 1961. The data represent operations of two additional airplane types and several additional operators. Inasmuch as the results for the two 3-month periods were very similar, the two sets of data have been combined and are presented in this paper.

SYMBOLS

M_{NE}	placard never-exceed Mach number (ref. 2)
M_{NO}	placard normal-operating limit Mach number (ref. 2)
V_{NE}	placard never-exceed speed, knots (ref. 2)
V_{NO}	placard normal-operating limit speed, knots (ref. 2)

EVALUATION OF RECORDS

The results presented on the maximum speeds were evaluated according to the procedures given in reference 1. Briefly, these procedures consisted in dividing each flight into three segments designated as the climb, cruise, and descent flight conditions as illustrated in figure 1. (In this figure increasing altitude is shown by a downward deflection of the altitude trace, increasing airspeed by an upward deflection, and positive acceleration by downward deflection.) The climb covered the portion of flight from the take-off until the initial cruising altitude was reached; the cruise segment covered the essentially constant-altitude portion of the flight; and the descent covered the portion of flight from the end of cruise until the airplane landed. Both the climb and descent flight conditions occasionally included short periods when the airplane was in level flight while holding altitude as a result of operational or air-traffic control procedures. Also the cruise condition occasionally included periods when the airplane was climbing or descending to a different cruise altitude.

The VGH records covering each segment of each flight were examined to determine if the airplane exceeded the placards, V_{NO} or M_{NO}. The maximum speed and the altitude associated with each exceedance of the placard speed during the climb, cruise, and descent flight conditions were evaluated. By this procedure, each individual exceedance was counted as an event. Thus, each segment of a flight may have had no exceedances, one exceedance, or several exceedances. In addition, the time duration of each exceedance was determined by reading the length of time that the airspeed was in excess of the placard speed. The data obtained in the foregoing manner were used to determine the average number of flights required to exceed the placard speeds, and the average percent of the total flight time that the airplanes were operated at speeds in excess of the placard speeds.

RESULTS AND DISCUSSION

The maximum airspeed and the corresponding altitude for each exceedance of V_{NO} during the climb, cruise, and descent portions of flights are shown in figures 2 to 6 for each of the operations covered by the present analysis. The sizes of the record samples from which the overspeed data were evaluated are noted in each figure in terms of the flight hours and number of flights. Figures 2 to 4 pertain to operations of three types of turbojets, whereas figures 5 and 6 pertain to two types of turboprop transports. For comparison of the present results with those given in reference 1, it should be noted that airplane types designated I, IV, and V herein correspond to airplanes designated X, Y, and Z, respectively, in the reference. No additional data for airplane type VI (designated W in ref. 1) have become available since those reported in the reference and, consequently, no results for this type aircraft are given in this report.

Consideration of figures 2 to 6 shows that, in general, the airplanes exceeded the placard speeds most frequently and attained the highest values during the descent flight condition. The placards were exceeded least frequently during the cruise. For the three turbojet airplanes (figs. 2 to 4) the placard speed exceedances were confined almost entirely to the lower altitudes wherein the placard speeds are limited by dynamic-pressure considerations rather than at high altitudes where the placards are limited by compressibility or Mach number.

The results shown in figures 5 and 6 for the two turboprop airplanes indicate that overspeeds occurred in all three flight conditions in the case of airplane IV, but only during descent for airplane V. Overspeeds for airplane IV (fig. 5) were experienced in both the altitude regime limited by Mach number and that limited by dynamic pressure. In regard to the results for airplane IV, however, it should be mentioned that the present results were obtained during a period when the airplane was operating under restricted placard speeds. (For the unrestricted placard speeds, see those given for airplane Y in ref. 1.) The present data for airplane IV, therefore, are not thought to be applicable to the unrestricted airplane. For airplane V, the results in figure 6 indicate that overspeeds occurred only during descent and within the altitude range limited by dynamic pressure. For this operation however, all the flights were conducted below the altitude where the placard speeds are limited by Mach number, and consequently, the present data for airplane V should not be used to infer that overspeeds would not occur within the altitude range limited by Mach number.

The overspeed data reported in reference 1 show that overspeeds occurred throughout the operating altitude range for turboprop airplane types Y and W (airplane Y is airplane IV of this paper). On the basis of the present results and those of reference 1, it appears that the overspeeds on turbojet airplanes occur primarily within the altitudes where the placard speeds are limited by dynamic-pressure considerations, whereas the overspeeds on the turboprops may occur throughout the operating altitude range.

The overspeed data for each operation are summarized in table I in terms of the average number of flights required to exceed V_{NO} and V_{NE} and in terms of the percent of total flight time spent above the placard speeds. Excluding the results for airplane IV (which were taken while the airplane operated under restricted or reduced placards) the results in table I show that the number of flights required to exceed V_{NO} $\left(\text{or } M_{NO}\right)$ ranged from about 1.5 to 57, and that the percent of the total flight time spent above V_{NO} ranged from 0.005 to 0.66. Likewise, the average number of flights to exceed V_{NE} $\left(\text{or } M_{NE}\right)$ ranged from 37 to 97 for the several operations for which exceedances of V_{NE} were recorded on the VGH records. The percent of time flown above the never-exceed placard was quite small, varying from 0 to 0.02 percent.

For the four airplanes reported in reference 1, the average number of flights to exceed V_{NO} ranged from about 1 to 7 and the percent of time spent above V_{NO} ranged from about 0.1 to 2.0 percent. Comparison of these results with those in table I for present operations indicates that there has been no overall improvement in the overspeed problem since the period (1959 primarily) covered by the initial results given in reference 1. As was noted in reference 1, the frequency of exceeding the placard speeds $\left(\text{both } V_{NO} \text{ and } V_{NE}\right)$, in general, is significantly higher for the turbine airplanes than for past operations with piston-engine airplanes.

CONCLUDING REMARKS

Analysis of VGH records collected on three types of turbojet and two types of turboprop commercial transport airplanes between July 1960 and February 1961 indicates that the maximum speeds attained by the transports frequently exceed the placard normal-operating limit speed and, to a lesser extent, the placard never-exceed speed. From the overall viewpoint, the amount of overspeeding does not appear to have decreased between the time (1959) covered by the initial overspeed results and the period covered by the present results.

REFERENCES

1. Coleman, Thomas L., Copp, Martin R., and Walker, Walter G.: Airspeed Operating Practices of Turbine-Powered Commercial Transport Airplanes. NASA TN D-744, 1961.

2. Anon.: Airplane Airworthiness; Transport Categories. Civil Aero. Manual 4b, Federal Aviation Agency, May 1, 1960.

TABLE I.- SUMMARY OF DATA ON PLACARD SPEED EXCEEDANCES

Airplane designation (type-series)	Operator	Average number of flights to exceed V_{NO}	Percent of time flown above V_{NO}	Average number of flights to exceed V_{NE}	Percent of time flown above V_{NE}
I-A	E	2.35	0.35	38.3	0.004
I-A	F	1.49	.33	----	-----
I-C	E	2.77	.19	97	.001
I-C	F	1.50	.28	72	.002
II-B	C	5.41	.05	----	-----
II-A; II-B	G	3.18	.12	----	-----
II-C	E	15.1	.02	----	-----
II-C	H	57.0	.005	----	-----
III-A	I	1.61	.66	37	.02
IV-A	A	.36	3.5	11.7	.10
IV-A	C	.83	.82	----	-----
V-A	J	15.1	.13	----	-----

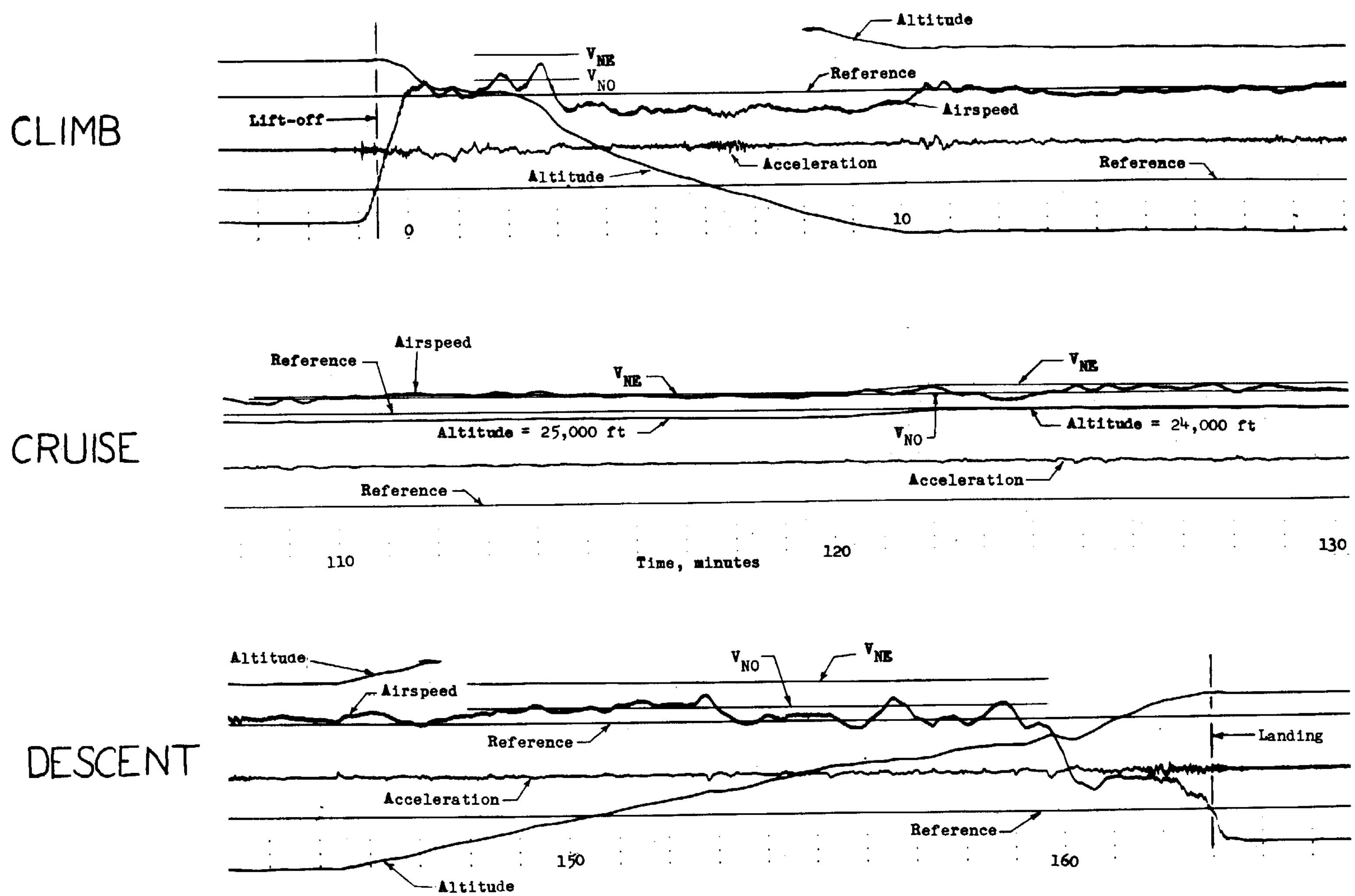
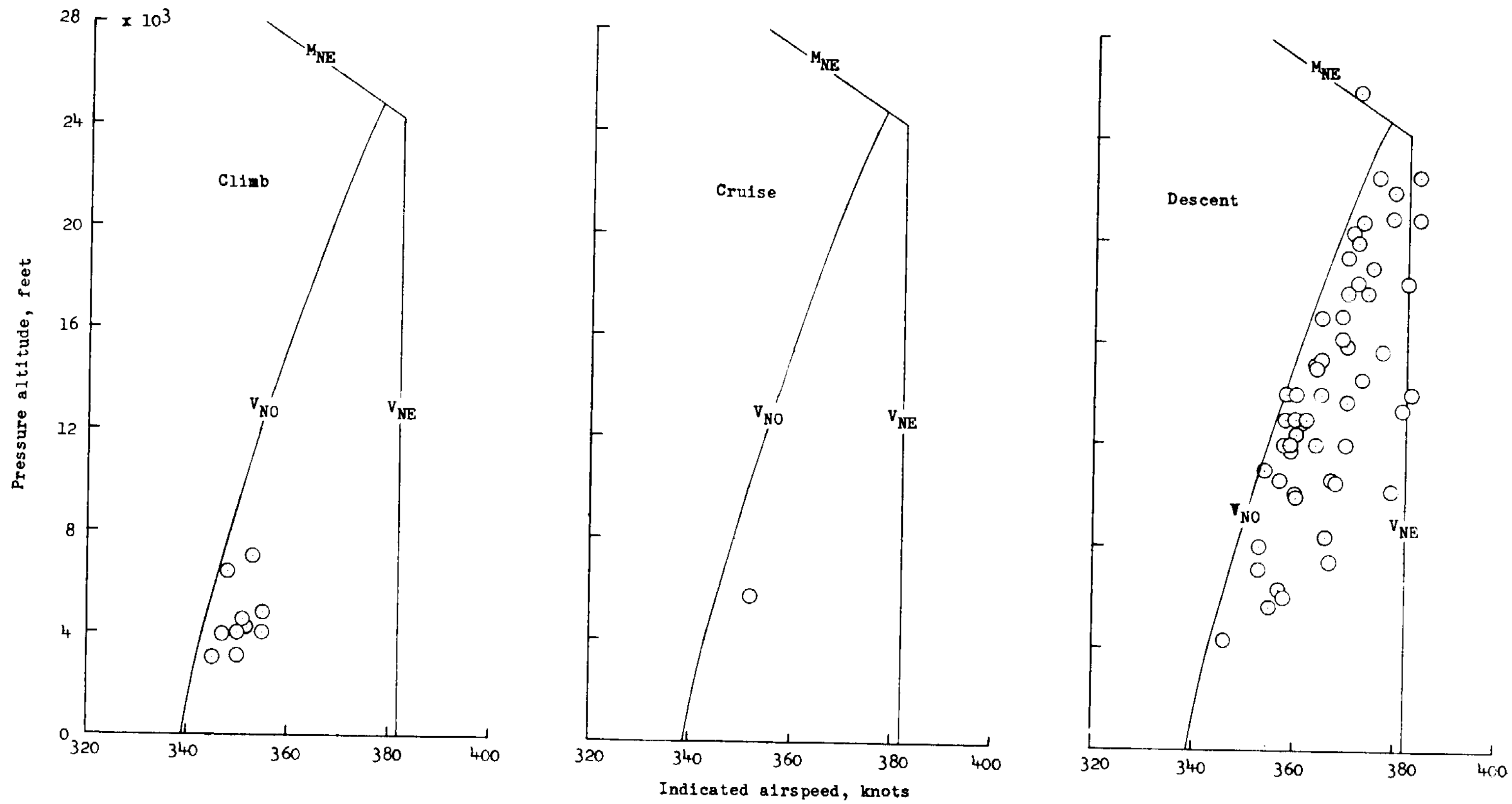
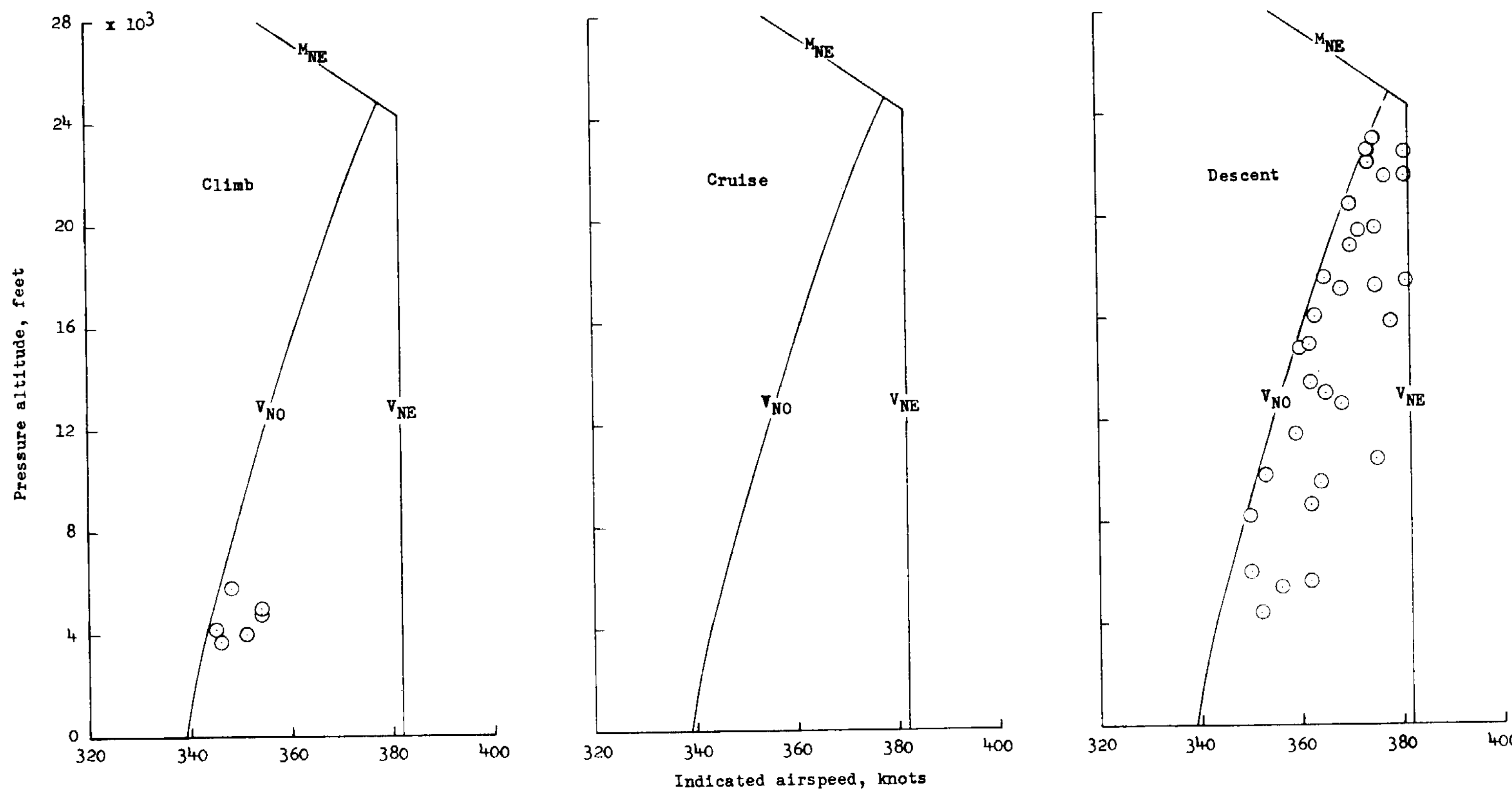


Figure 1.- Example of division of record for evaluation. Typical examples of overspeeds in each regime are shown.



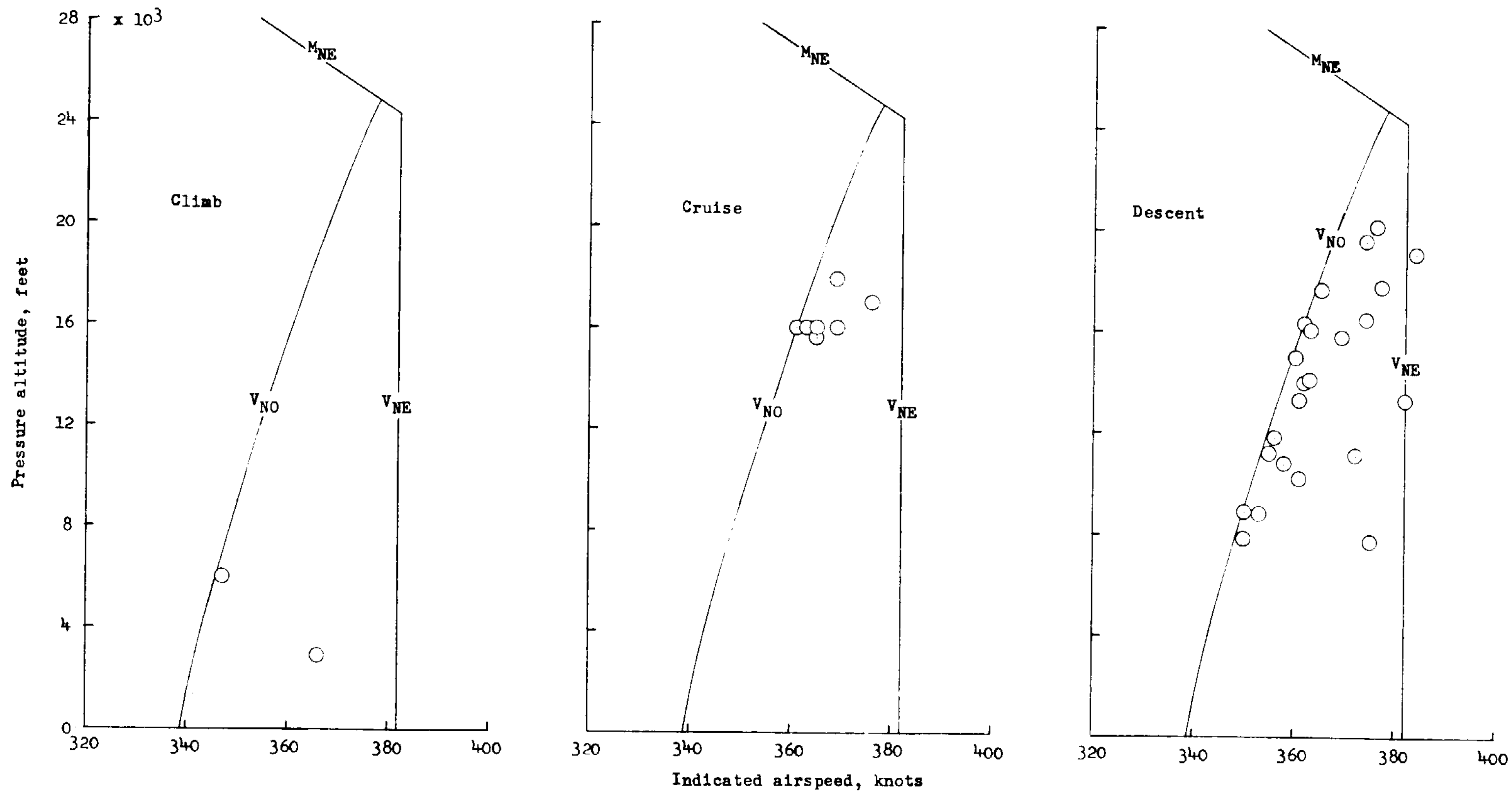
(a) Operator E, type I-A aircraft. 404.73 hours; 153 flights.

Figure 2.- Maximum airspeed and corresponding altitude for each placard speed exceedance during the climb, cruise, and descent portions of flight for type I aircraft.



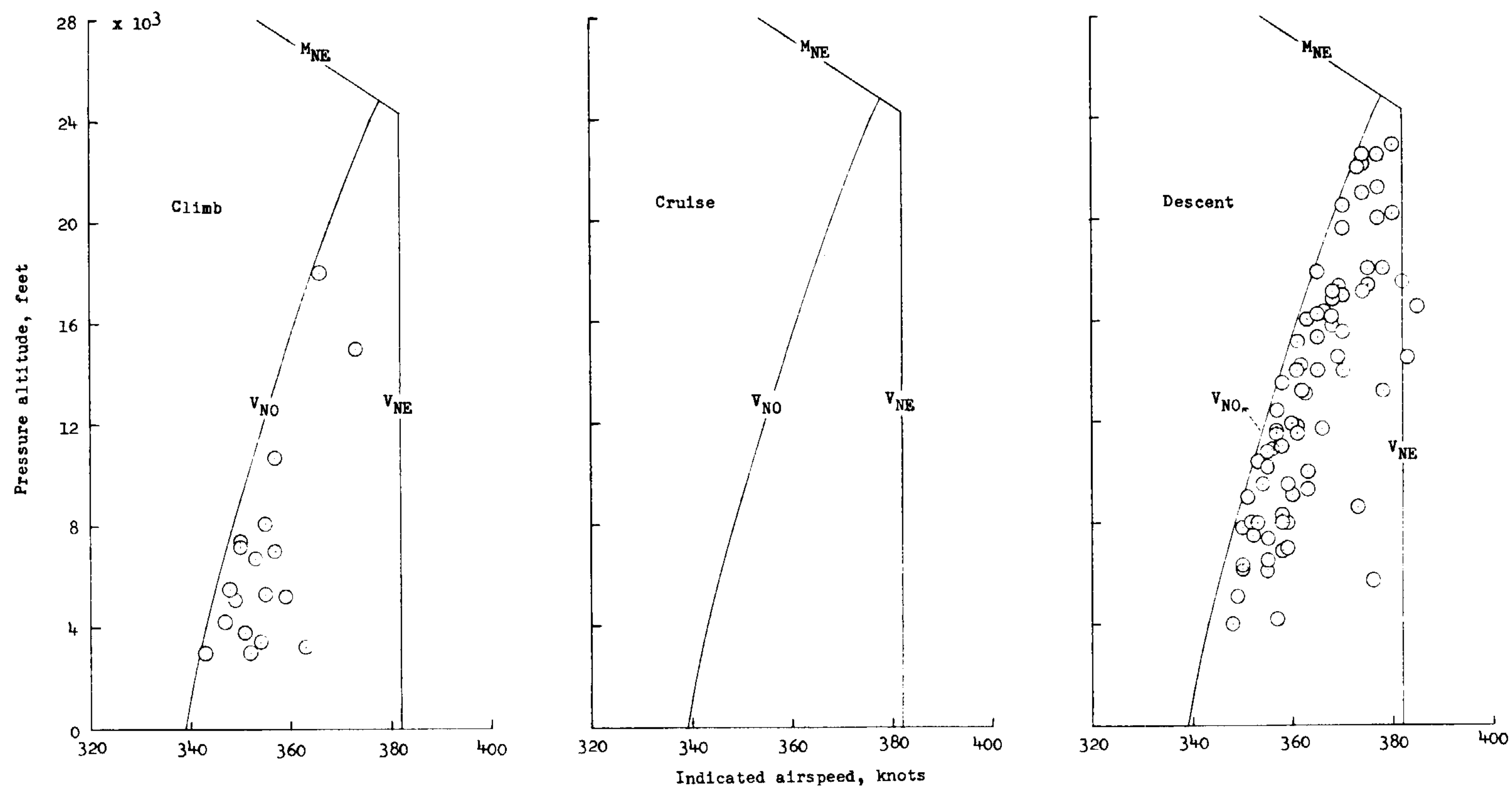
(b) Operator F, type I-A aircraft. 161.30 hours; 55 flights.

Figure 2.- Continued.



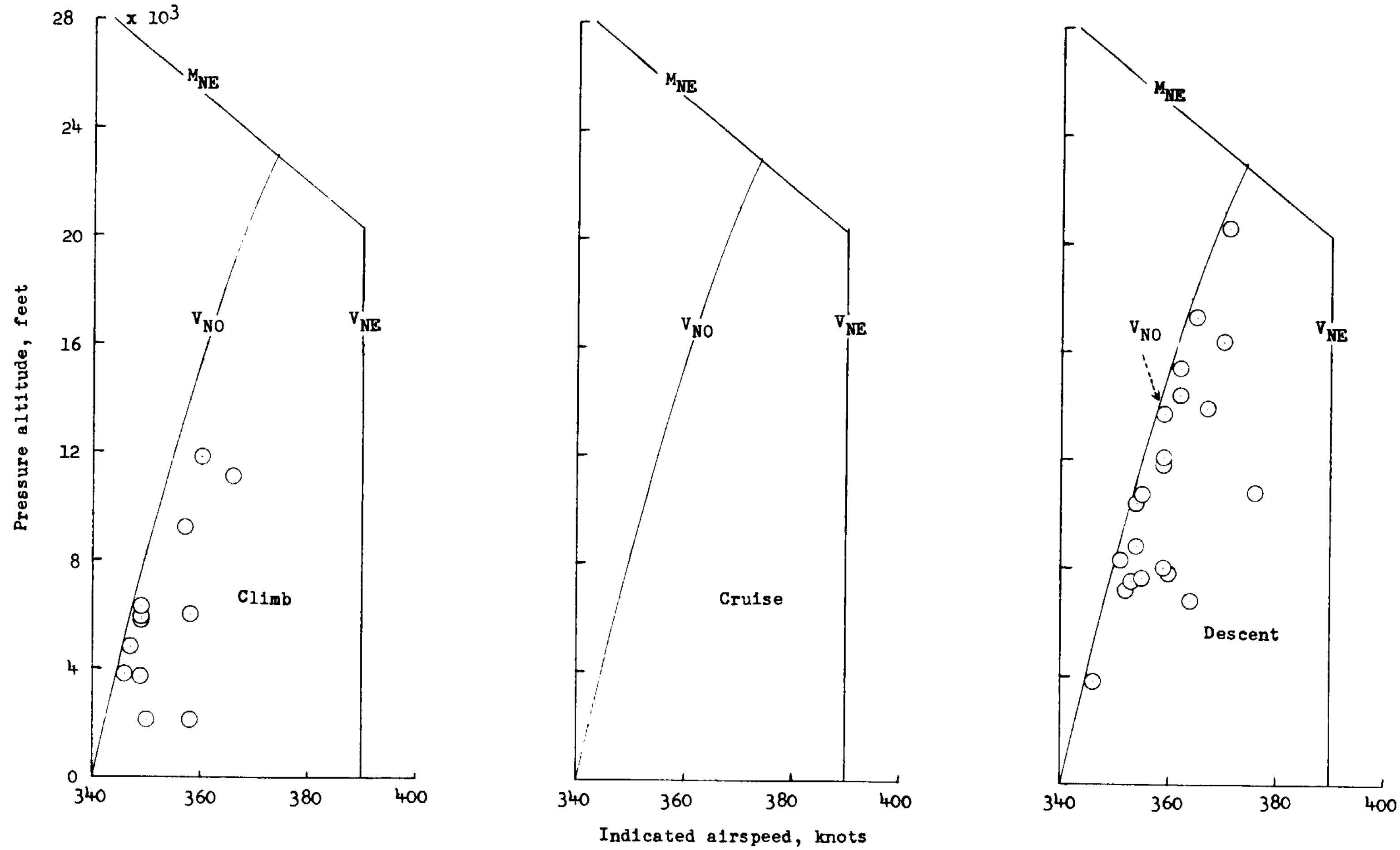
(c) Operator E, type I-C aircraft. 314.67 hours; 97 flights.

Figure 2.- Continued.



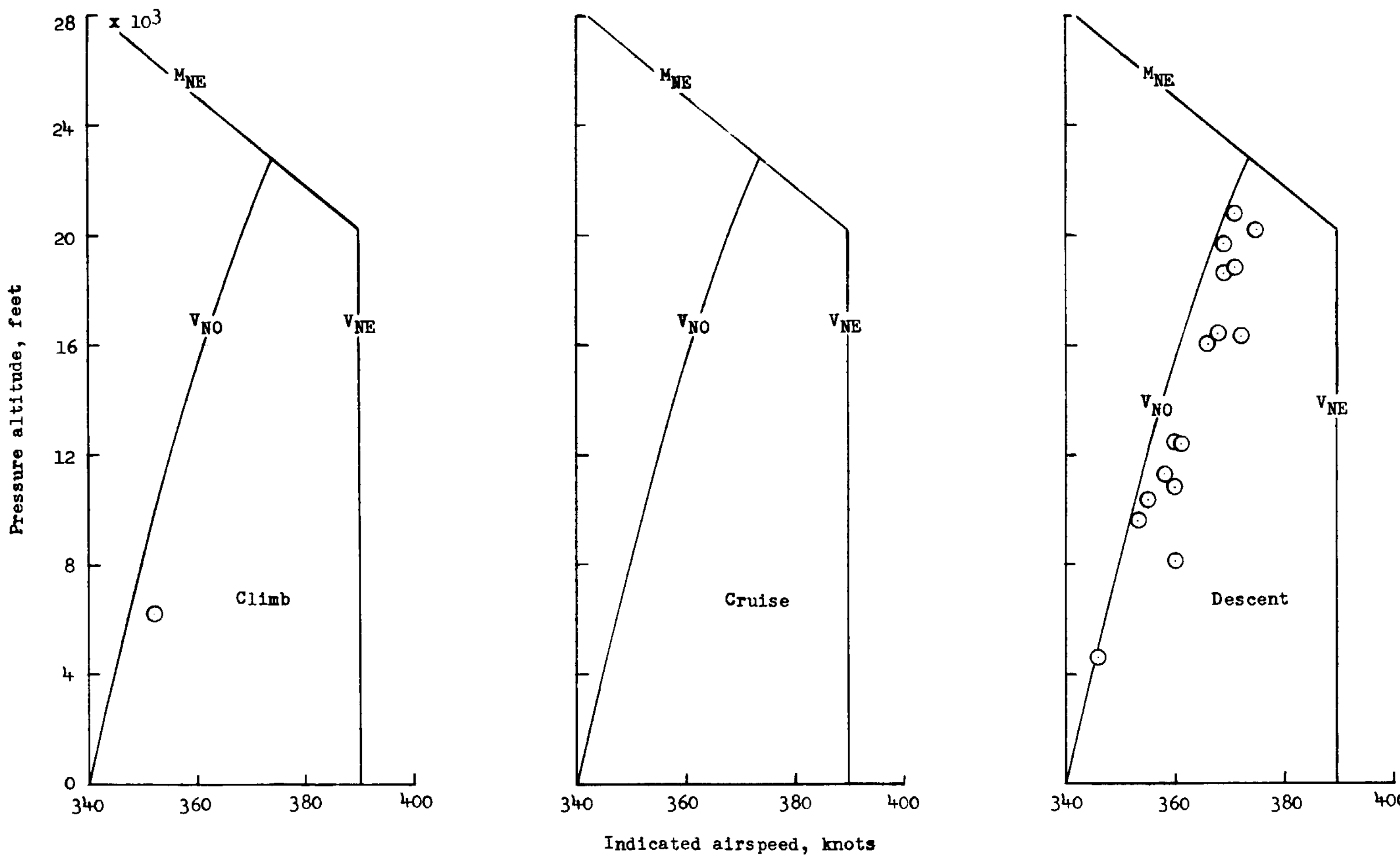
(d) Operator F, type I-C aircraft. 494.65 hours; 144 flights.

Figure 2.- Concluded.



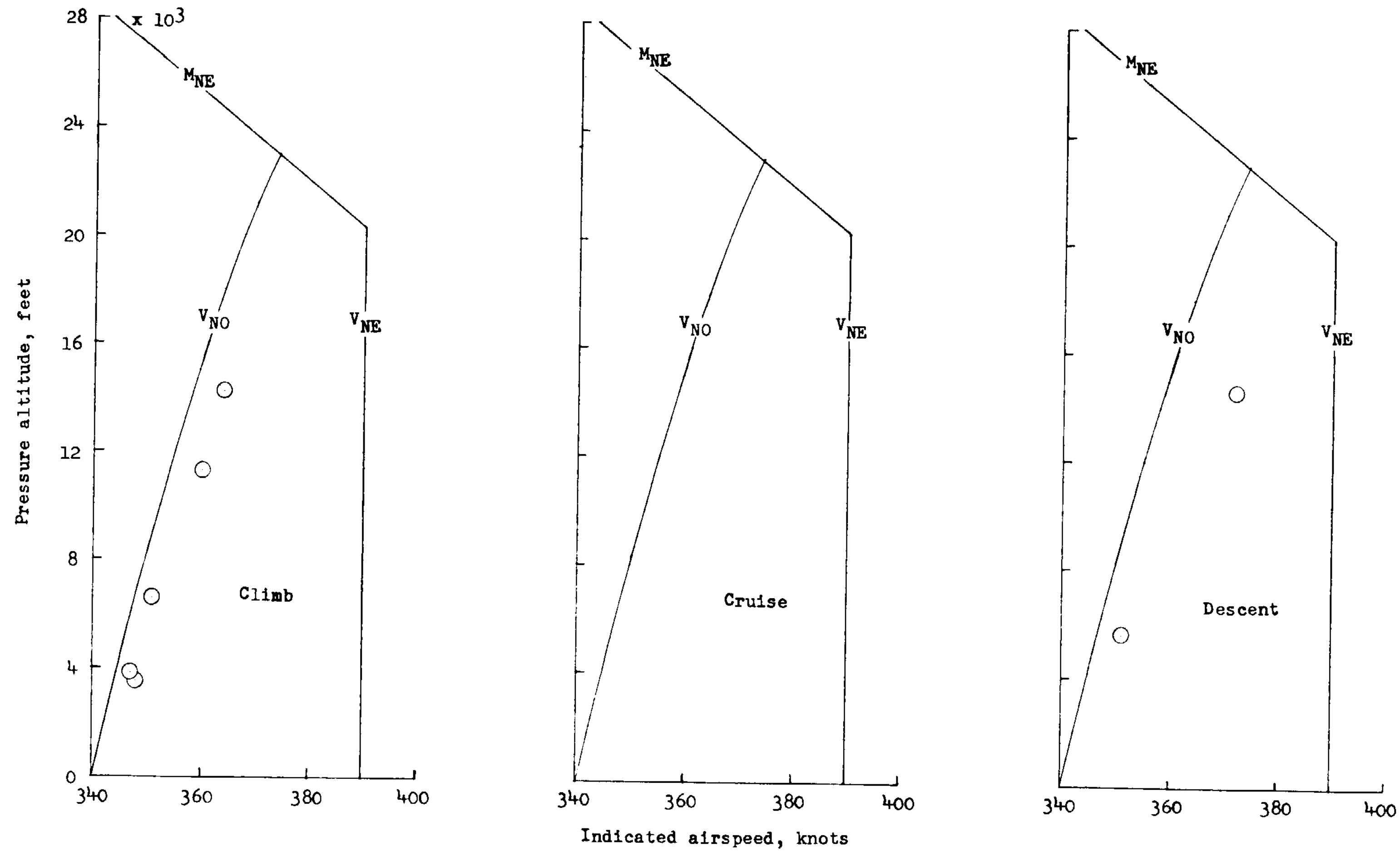
(a) Operator C, type II-B aircraft. 399.65 hours; 184 flights.

Figure 3.- Maximum airspeed and corresponding altitude for each placard speed exceedance during the climb, cruise, and descent portions of flight for type II aircraft.



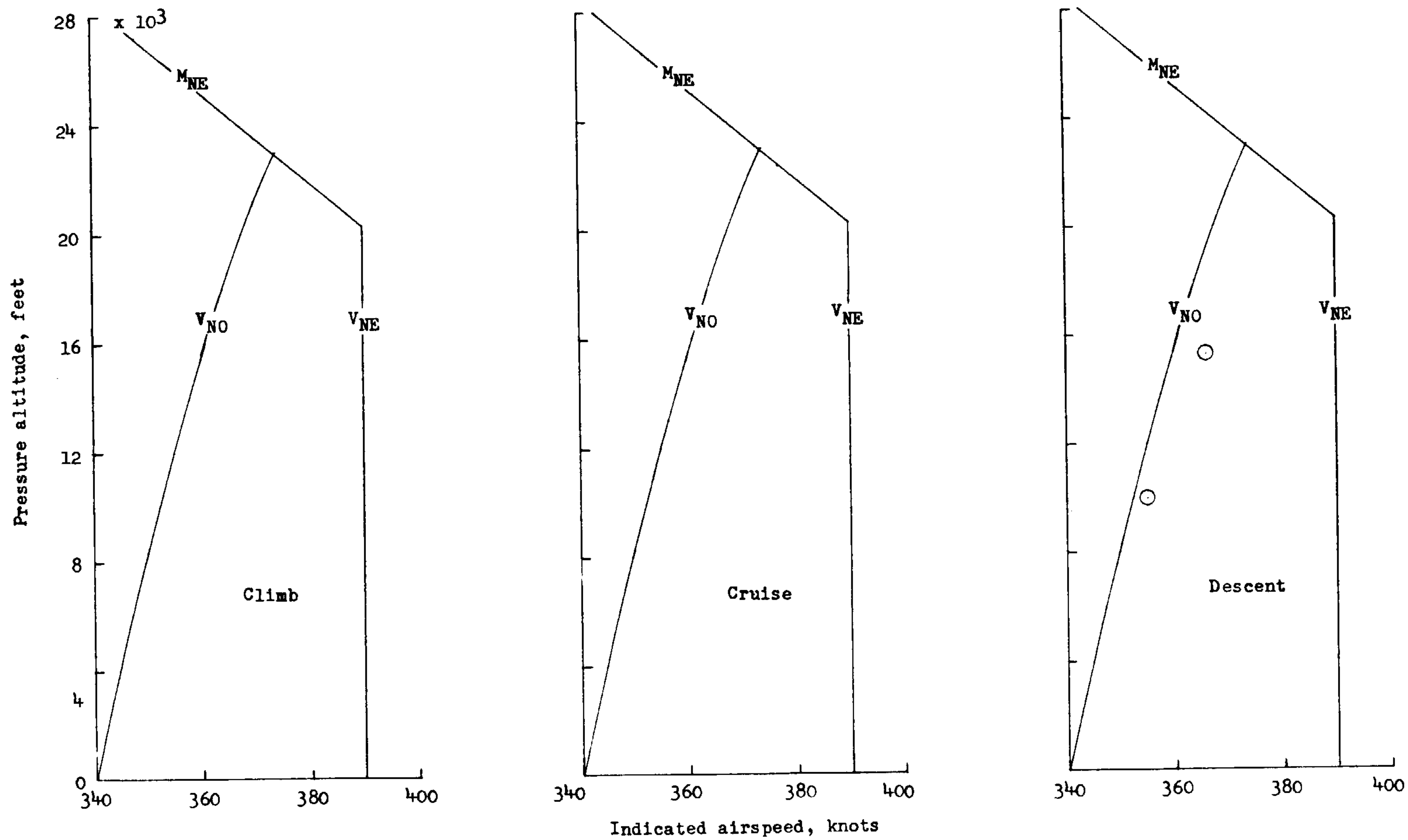
(b) Operator G, types II-A and II-B aircraft. 192.52 hours; 54 flights.

Figure 3.- Continued.



(c) Operator E, type II-C aircraft. 284.70 hours; 106 flights.

Figure 3.- Continued.



(d) Operator H, type II-C aircraft. 318.55 hours; 114 flights.

Figure 3.- Concluded.

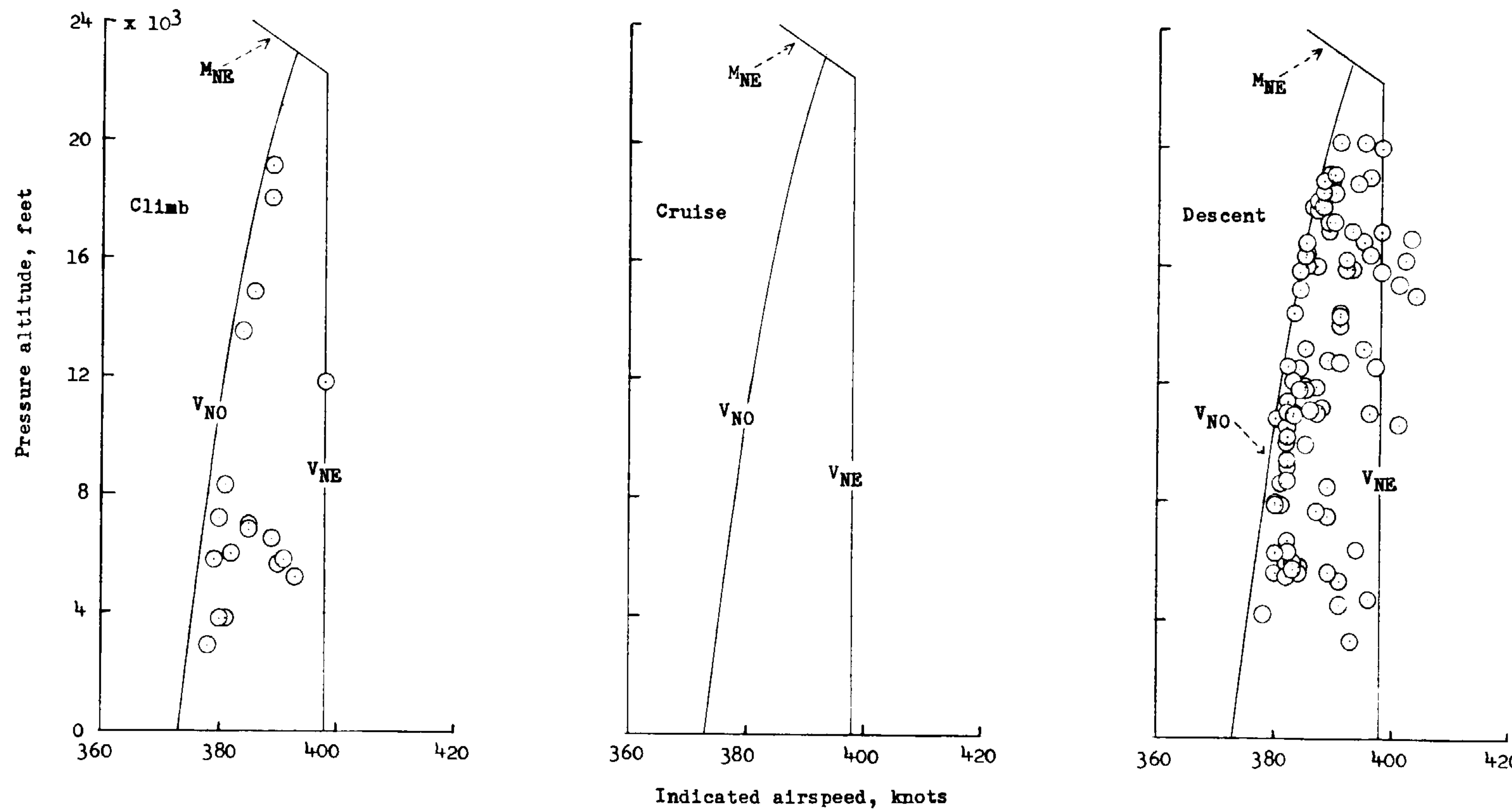
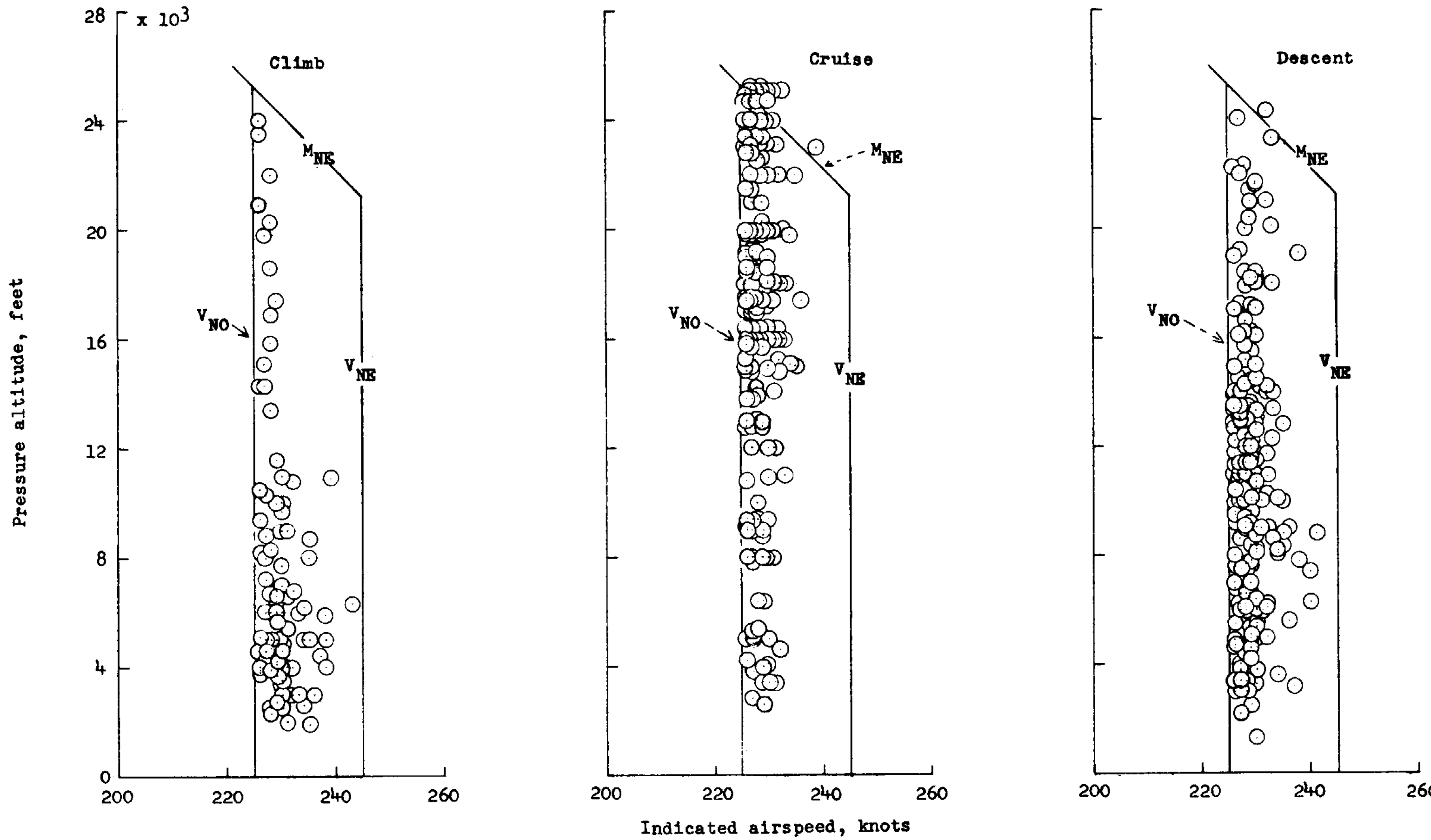
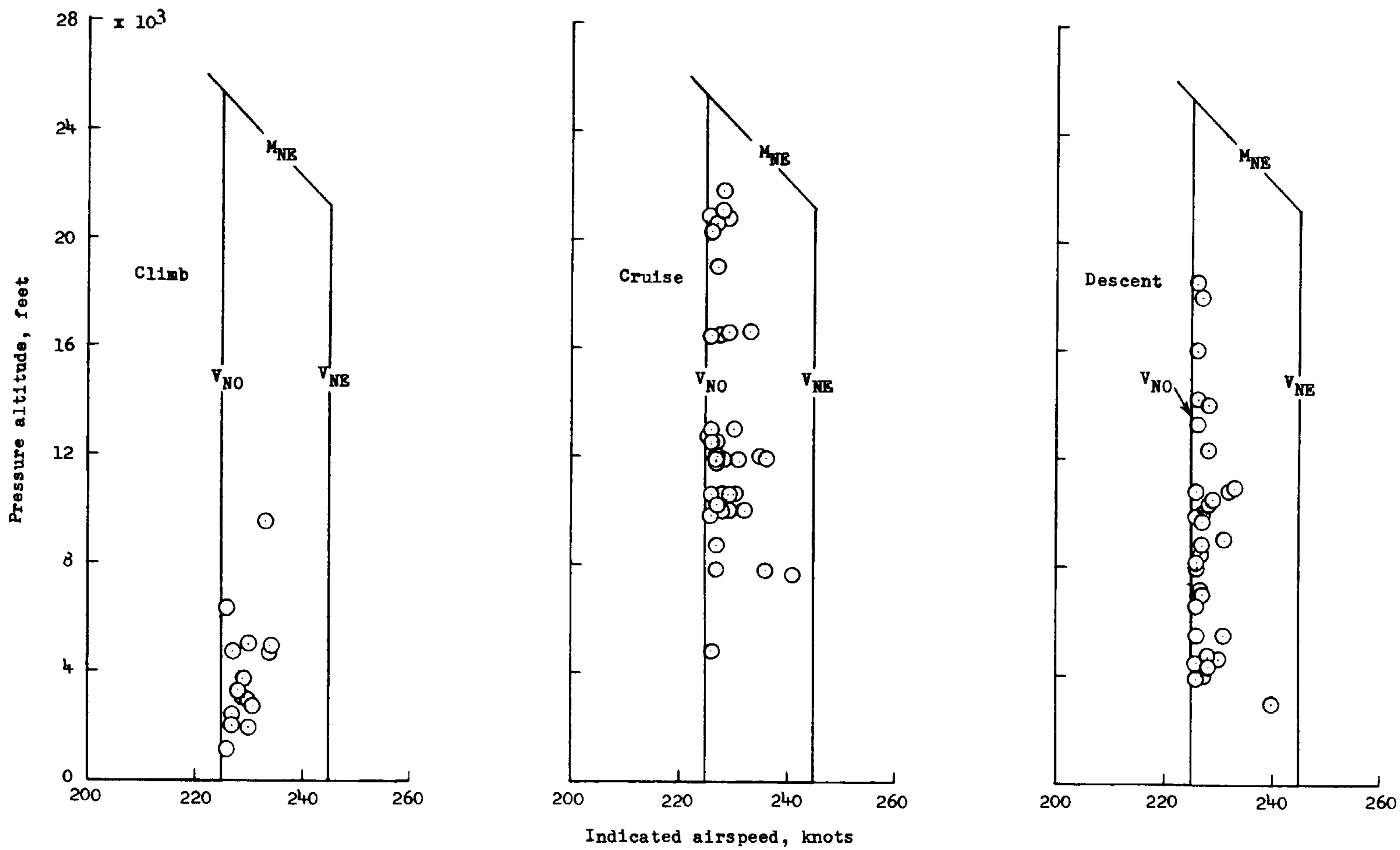


Figure 4.- Maximum airspeed and corresponding altitude for each placard speed exceedance during the climb, cruise, and descent portions of flight for type III-A aircraft. Operator I; 283.31 hours; 181 flights.



(a) Operator A, type IV-A aircraft. 305.19 hours; 245 flights.

Figure 5.- Maximum airspeed and corresponding altitude for each placard speed exceedance during the climb, cruise, and descent portions of flight for type IV aircraft.



(b) Operator C, type IV-A aircraft. 100.47 hours; 80 flights.

Figure 5.- Concluded.

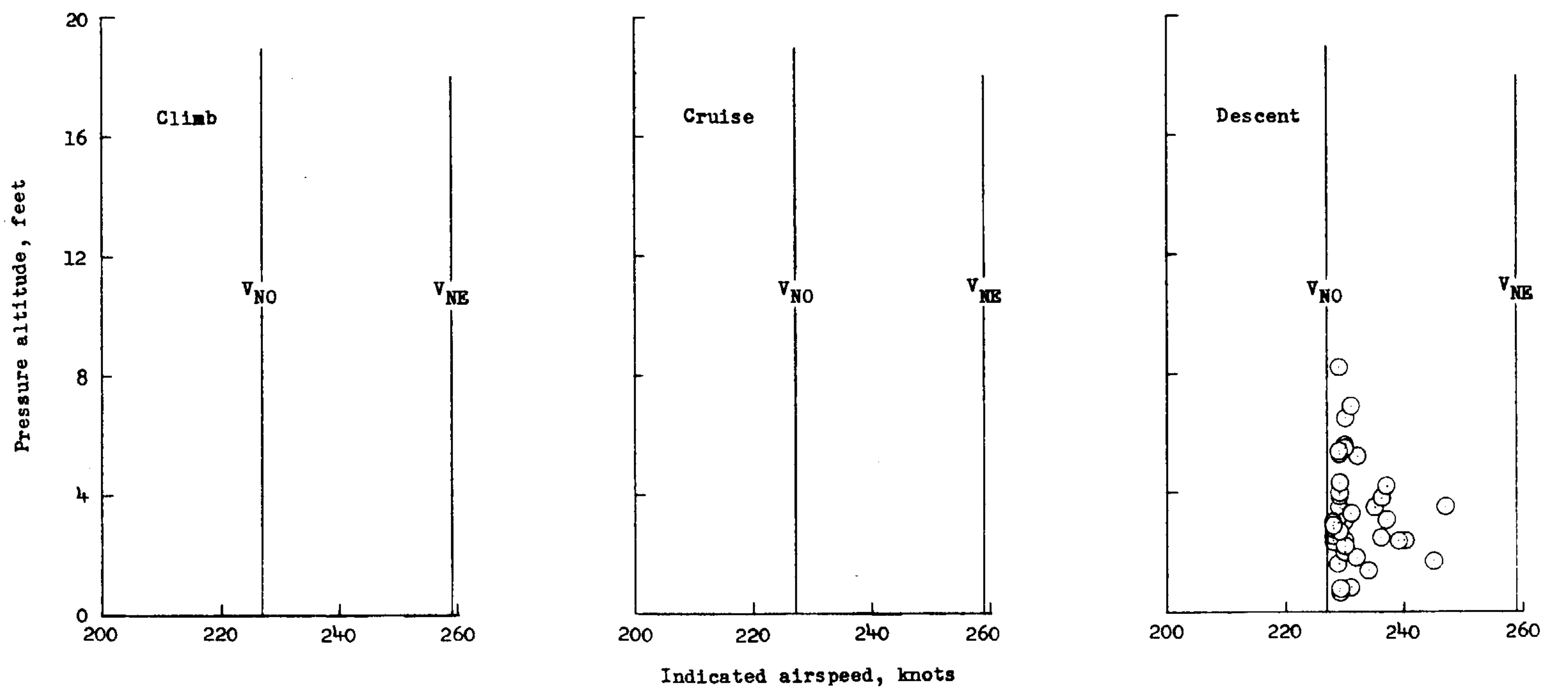


Figure 6.- Maximum airspeed and corresponding altitude for each placard speed exceedance during the climb, cruise, and descent portions of flight for type V-A aircraft. Operator J; 248.66 hours; 604 flights.

generally considered to be of no significance. The oscillations on the new class of aircraft, the turbine-powered aircraft, may therefore be considered a new experience that requires evaluation. The purpose of this paper is to describe the characteristics of these oscillations (period, amplitude, percent of flight time they occur, etc.) and to indicate some of the causes where they are known.

SYMBOLS

a_n	increment of normal acceleration, g units
$a_{n,max}$	maximum increment of normal acceleration, g units
g	unit of acceleration, 32.2 ft/sec^2
h	altitude, ft
M	Mach number
P	period, sec
V	indicated airspeed, knots

SAMPLE RECORDS OF OSCILLATIONS

In order to provide a basis for comparison in the description of oscillatory records, figure 1 is presented as a sample of portions of a flight on which no oscillations occurred. Shown are the take-off and climb (fig. 1(a)), cruise (fig. 1(b)), and descent and landing (fig. 1(c)). Increasing altitude is indicated by a downward deflection of the altitude trace; increasing indicated airspeed, by an upward deflection of the airspeed trace; and increasing normal acceleration at the center of gravity, by a downward deflection of the acceleration trace from the 1.0g level. The record of figure 1 shows two traces for the airspeed and two for the altitude during take-off and landing. Each trace covers a different range of airspeed or altitude. When one trace of a given pressure element goes off scale another comes on. The record also shows two reference lines from which the traces are read. Timer marks are shown along the bottom of the record as vertical dashed lines, the time interval between two successive vertical dashed lines being 1 minute. The time in minutes from take-off is indicated along the bottom of the record.

A few sample records of oscillations for various types of turbine-powered aircraft are shown in figures 2 to 7. The various samples for a

V. SOME OSCILLATORY CHARACTERISTICS OBSERVED ON TURBINE-POWERED AIRCRAFT DURING COMMERCIAL OPERATIONS

By Milton D. McLaughlin

SUMMARY

Oscillatory motions as observed on VGH records from three types of turbojet and three types of turboprop transports in commercial operation are described and analyzed. Two types of oscillations were generally observed. One was a continuous type which was evident primarily as an oscillation in normal acceleration at the center of gravity and had low amplitudes (±0.05g to ±0.2g from 1.0g level) and long periods (generally 6 to 20 seconds). The other was a divergent or convergent type in which oscillations in accelerations reached values as high as 0.9g and -0.8g from the 1.0g level. The continuous type persisted from a few minutes to several hours whereas the duration of the divergent or convergent type was usually of the order of 1 minute. The altitude and speed deviations corresponding to the continuous type of oscillations were rather small. For the divergent or convergent type, however, the overall variations in altitude were as much as 1,000 feet and in indicated Mach number and airspeed as much as 0.08 and 30 knots, respectively. The percent of flight time that the two types of oscillations occurred ranged from as low as 0.2 percent for one type of aircraft to as high as 13.5 percent for another type (each type having from one to seven aircraft).

INTRODUCTION

When the current VGH program on turbine-powered transports was initiated a number of years ago oscillatory motions in the longitudinal mode were observed to occur rather frequently on one type of turboprop transport. These oscillations were noted primarily in the oscillations of the normal (or vertical) acceleration trace of the VGH recorder and to a lesser extent in the less sensitive pressure-altitude trace. On occasions these oscillations were also reflected in the airspeed trace. As more aircraft were instrumented in the program, oscillatory motions were observed on other types of turboprop aircraft and on turbojet aircraft. These oscillations were unusual in the sense that in some cases the amplitudes in acceleration built up to about ±0.9g (from the 1.0g level) in a few cycles and in other cases the oscillations frequently persisted at lower amplitudes for periods up to several hours. In previous VGH programs conducted on piston-engine aircraft, oscillations were noted only rarely and even then were of such low amplitude that they were given aircraft type do not necessarily represent the same aircraft. All of the samples shown are for passenger-carrying flights only. Oscillations have been observed to occur during climb, cruise, and descent, although the majority of the cases were in the cruise portion of flight. The oscillations also occurred with autopilot on and off. Except for the cases where the aircraft were known to be operating either without an autopilot installed or with the autopilot unoperative, information on whether the autopilot was engaged or disengaged was not generally available and had to be surmised from the character of the altitude trace. Experience of NASA pilots in flying transport aircraft indicated that altitude excursions in manual control were many times those with the autopilot engaged. This was also indicated in the examination of VGH records for aircraft with and without autopilots. Hence it was assumed that when the altitude trace was a straight line, except for small deviations due to oscillations, the aircraft was on autopilot in the altitude-hold mode.

Type I Aircraft

The records of figure 2 show several samples of essentially constant-frequency and constant-amplitude oscillations. (See figs. 2(a) to 2(d).) The periods range from about 8 to 20 seconds and the amplitudes from about $\pm 0.05g$ to $\pm 0.2g$. The wave forms are both symmetric (sinusoidal, saw tooth) and asymmetric. The time that the oscillations persisted ranged from a few minutes to several hours. For example, for the flight represented by figure 2(c) the oscillations continued for about $6\frac{1}{2}$ hours of the $7\frac{1}{2}$-hour flight.

Examples of divergent and convergent types of oscillations are shown in figures 2(e) to 2(h). The oscillations generally lasted less than 2 minutes. The amplitudes reached values as high as $+0.8g$ and $-0.7g$ with a period of about 22 seconds. (See fig. 2(g).) During the oscillations shown in figure 2(g) the total variation in the indicated pressure altitude was about 600 feet. Variations in indicated airspeed during oscillations are evident in both figures 2(f) and 2(g). In figure 2(f) the indicated Mach number was 0.83 ($V = 280$ knots) before the oscillation and varied from 0.79 ($V = 265$ knots) to 0.87 ($V = 295$ knots) during the oscillations. The divergent or convergent oscillations of figures 2(e) to 2(h) show evidence of originating in light turbulence (indicated by the high-frequency hash on both the airspeed and altitude traces).

Type II Aircraft

The time histories of figures 3(a) to 3(e) show some samples of essentially constant-frequency, constant-amplitude acceleration oscillations for type II aircraft with the autopilot presumably in operation in the altitude-hold mode. The periods for the various types of oscillations range from about 11 to 37 seconds and amplitudes from ±0.05g to ±0.2g. The wave forms are both of the asymmetric and nearly symmetric types. The oscillations persisted from a few minutes to as long as $5\frac{3}{4}$ hours (at an amplitude of about ±0.15g) for one flight of 8-hour duration.

Examples of divergent oscillations for type II aircraft are shown in figures 3(f) to 3(h). These oscillations in accelerations reached values as high as +0.4g and -0.5g. (See fig. 3(h).) The overall changes in the indicated pressure altitude resulting from the divergent oscillations amounted to as much as 970 feet at an altitude of 9,700 feet (fig. 3(f)) and 925 feet at an altitude of 25,000 feet (fig. 3(g)). The indicated airspeed (and Mach number) varied from 333 knots ($M = 0.59$) to 361 knots ($M = 0.64$) for the divergent oscillation of figure 3(f) and from 335 knots ($M = 0.80$) to 352 knots ($M = 0.83$) for figure 3(g).

Type III Aircraft

Examples of oscillatory accelerations on type III aircraft are shown in figure 4. For the records shown, the aircraft were not equipped with autopilots. In general, the oscillations are irregular in wave form and variable in frequency and amplitudes. The amplitudes range from about ±0.1g (figs. 4(b) and 4(c)) to +0.4g and -0.3g (fig. 4(f)).

Type IV Aircraft

Samples of oscillatory accelerations for type IV aircraft are shown in figure 5. The samples of figures 5(a) and 5(b), for which the autopilot was known to be inoperative, show random amplitude accelerations having periods ranging from 5 to 9 seconds. The oscillations in some portions of the record shown in figure 5(b) are superimposed on maneuver accelerations (turns). Occasionally the amplitude reached values of ±0.5g. In figure 5(c) the oscillations were more regular in patches and had a period of about 9 seconds with one patch having acceleration amplitudes as high as ±0.5g. In this case it appears that the autopilot may have been in operation for the short time corresponding to the patches. A convergent type of oscillation is shown in figure 5(d) in which accelerations of 0.9g and -0.8g were reached. The overall altitude variation was about 350 feet.

(c) Electric power amplification

(d) Friction

(e) Gain - low damping on high gain

(f) Servo clutches - hanging

(g) Limited control power available at high speeds

In regard to the control system, the principal causes given were: (a) high friction in bearing, linkages, boost valves, and so forth, and (b) excessive wear or play in linkages or bearings. Another contributing factor that has been mentioned is the dynamic stability characteristics of the turbine-powered aircraft. These newer aircraft are flying faster and higher which, with the attendant reduction in damping, may be expected to make them more sensitive to oscillations induced by the autopilot and control system.

In examining the histories of oscillations from each VGH record received it was observed that for a number of aircraft the percent of flight time that the oscillations occurred varied over a long period (several months) - staying high for a period, dropping off to a low value, and then increasing again after several months. This variation is believed to be associated with periodic maintenance of the autopilot and control system. In one case where an airline was contacted when the frequency of occurrence of the oscillations dropped off markedly, it was found that during the maintenance performed at this time a control link with excessive wear in the bearing was replaced. The variation in the percent of flight time that oscillation occurred on this airplane is shown in figure 8. The width of the bars in the figure represents the time period covered by each VGH record. The large variation in the occurrence of oscillations is clearly evident in the figure.

While maintenance in general may be expected to reduce the occurrence of oscillations, one operator indicated that the occurrence of oscillations actually increased following maintenance.

STATISTICS OF OSCILLATIONS

Analysis of the flight conditions at which oscillations were observed indicated that in general there was no relation between Mach number, airspeed, and altitude and the occurrence of the oscillations. Oscillations occurred in climb, cruise, and descent. They occurred with autopilot engaged and for some aircraft with the autopilot inoperative.

Type V Aircraft

Samples of acceleration oscillations of essentially constant amplitudes but variable frequency are shown in figures 6(a) and 6(b) for type V aircraft. The period of the oscillations varies from about 3 to 6 seconds in figure 6(a) and from about 8 to 16 seconds in figure 6(b). An interesting oscillation in airspeed and acceleration is shown in figure 6(c). In this case the airspeed varied about 20 knots over a period of about 85 seconds. The oscillation in acceleration increased in frequency and amplitude as the speed increased and decreased in frequency and amplitude as the speed decreased. During the period of the oscillation in airspeed, the altitude varied by as much as 120 feet. An example of a divergent-convergent type of acceleration oscillation in turbulence is shown in figure 6(d). The amplitude reached a value of ±0.5g. The overall change in altitude amounted to about 300 feet.

Type VI Aircraft

Sample oscillatory records for type VI aircraft are shown in figure 7. In figure 7(a) patches of oscillatory accelerations are shown having two different periods, 3 and 7 seconds, and amplitudes up to ±0.15g. Constant-amplitude oscillations of ±0.15g and a period of 9 seconds are shown in figure 7(b) and oscillations occurring in light turbulence and having amplitudes up to ±0.25g and a period of about 7 seconds are shown in figure 7(c). A divergent oscillation having an amplitude of +0.4g and -0.3g and a period of about 14 seconds followed by a low-amplitude, small-period (3 seconds) oscillation is shown in figure 7(d). Also shown in this figure are other patches of constant-amplitude oscillations having periods of 8 and 16 seconds.

SOURCES OF OSCILLATIONS

In discussions held with various airline operators and manufacturers concerning the oscillations a number of causes originating in either the autopilot or the control system or both were given. Some of the sources of autopilot-induced oscillations included:

(a) Air-data computer - difficulties with electrical amplifiers, shaping networks, and so forth

(b) Air-data and attitude sensors - lag in tubing from pressure sensors, mismatched accelerometers, malfunction of attitude gyros

The percent of flight time that the oscillations occurred for various types of aircraft is shown in table I. In this table the number of operators and the number of aircraft of a given type are indicated. The percent of flight time that the oscillations occurred is shown as range (lowest to the highest) for the various aircraft of a given type and as an average for all aircraft of a given type considered collectively. The average percent of flight time that the oscillations occurred for various types of aircraft ranged from about 0.2 to 13.5 percent. Individual aircraft of a given type showed a much greater spread. Type I aircraft, for example, ranged from 0.3 to 26.3 percent and type II, from 2.3 to 21.4 percent.

The distribution of the percent of flight time that oscillations occurred on 17 aircraft (types I, II, III, and V) is shown in figure 9. Of the 17 aircraft 10 oscillated between 0 and 5 percent of the time, 3 between 5 and 10 percent, 1 between 15 and 20 percent, 2 between 20 and 25, and 1 between 25 and 30 percent.

The percent of flight time that various values of normal acceleration at the center of gravity were exceeded during the oscillations is shown in figure 10. The curves for each aircraft type are based on information for two or more aircraft. The data of figure 10 do not include the large divergent-convergent type of oscillations which at times for some aircraft reached values of about ±0.9g. The oscillatory experience for the several types of aircraft may be seen to be very nearly the same.

The cumulative-frequency distribution of oscillatory accelerations per mile of flight is shown in figure 11 for five aircraft types. The range in the number of oscillatory accelerations per mile of flight for the various aircraft types is less than an order of magnitude.

Some idea of how the oscillatory accelerations compare with the maneuver and gust accelerations encountered on piston-engine aircraft may be obtained from figure 12. The oscillatory-acceleration experience for the various types of turbine aircraft may be seen to be less than the maneuver- and gust-acceleration experience for piston-engine aircraft. As pointed out previously, however, the oscillatory experiences of various aircraft of the same type can vary appreciably. The oscillatory-acceleration experience of 16 turbine aircraft considered individually was therefore plotted in figure 13 for comparison with the maneuver-acceleration experience of piston-engine aircraft. Some of the turbine aircraft apparently had oscillatory-acceleration experiences bordering on the maneuver-acceleration experience of piston-engine aircraft.

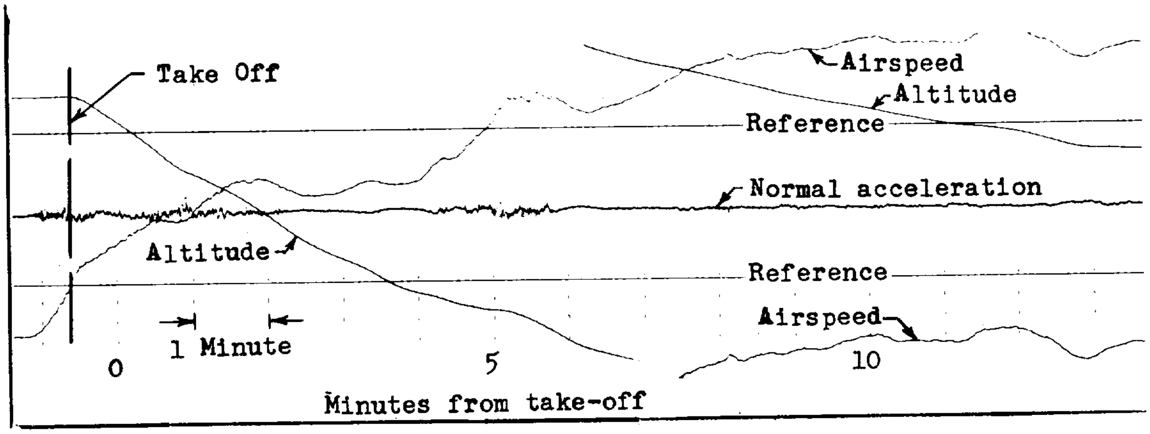
CONCLUDING REMARKS

Two types of oscillations were generally observed in the VGH records taken from three types of turbojet and three types of turboprop transports in commercial operations. These oscillations were noted both with and without autopilot. One was a continuous type which was evident primarily as an oscillation in normal acceleration at the center of gravity and had low amplitudes (±0.05g to ±0.2g from the 1.0g level) and long periods (generally 6 to 20 seconds). The other was a divergent or convergent type in which oscillations in accelerations reached values as high as 0.9g and -0.8g from the 1.0g level. The continuous type persisted from a few minutes to several hours whereas the duration of the divergent or convergent type was usually of the order of 2 minutes or less. The percent of flight time that the oscillations occurred ranged from as low as 0.2 percent for one type of aircraft to as high as 13.5 percent for another type (the results for each type being based on one to seven aircraft). Individual aircraft of a given type have also shown a large spread in the percent of oscillatory experience, ranging for example from as low as 0.3 percent for one aircraft to as high as 26.3 percent for another. Some of the aircraft had oscillatory-load experience that was about the same as the maneuver-load experience for some of the piston-engine transports.

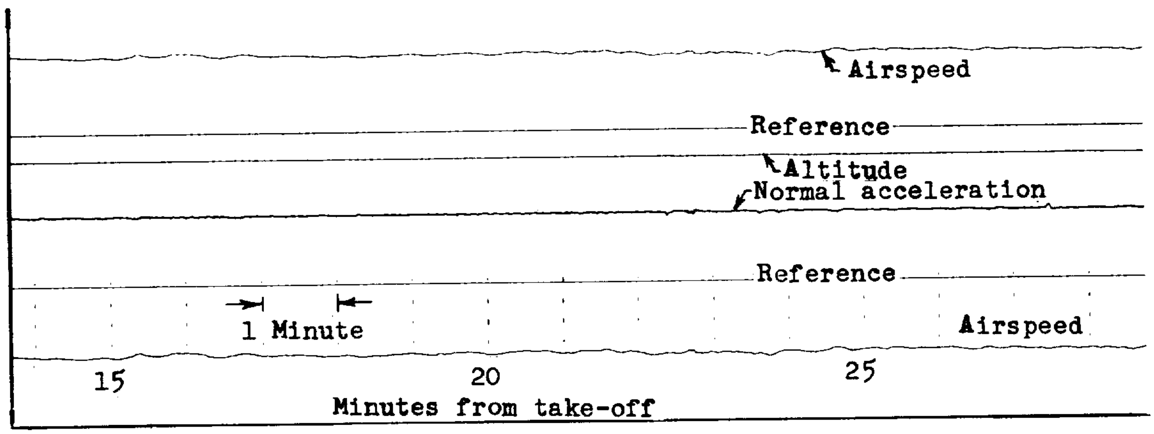
The altitude and speed deviations corresponding to the continuous type of oscillation were rather small. For the divergent or convergent type, however, the overall variations in altitude were as much as 970 feet and in indicated Mach number and airspeed as much as 0.08 and 30 knots, respectively.

TABLE I.- PERCENT OF FLIGHT TIME THAT OSCILLATIONS OCCURRED

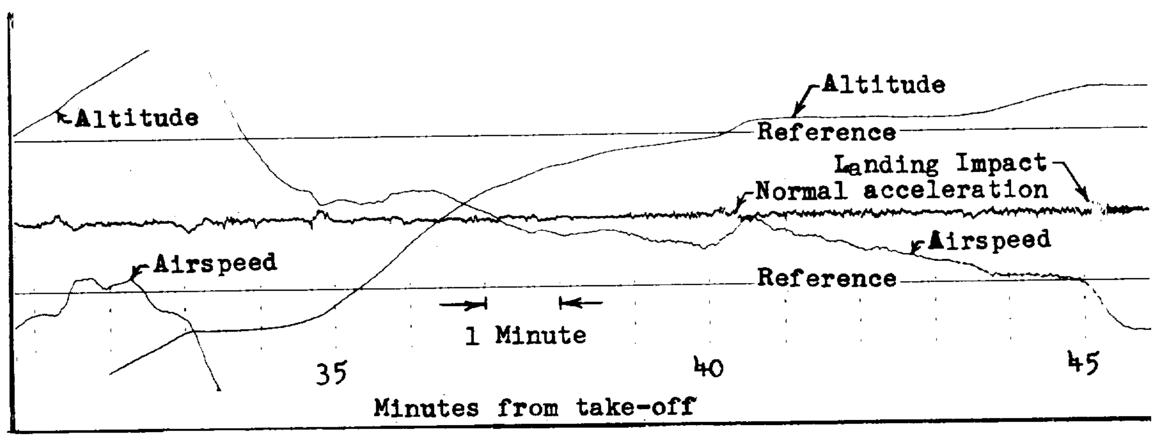
Aircraft designation	Number of operators	Number of aircraft	Percent of total flight time	
			Range	Average
I	3	6	0.3 to 26.3	3.6
II	4	7	2.3 to 21.4	13.5
III	1	2	.7 to 6.5	4.3
IV	2	4	1.8 to 2.0	1.9
V	1	2	3.1 to 5.1	4.1
VI	1	1	.2	.2



(a) Take-off and climb.

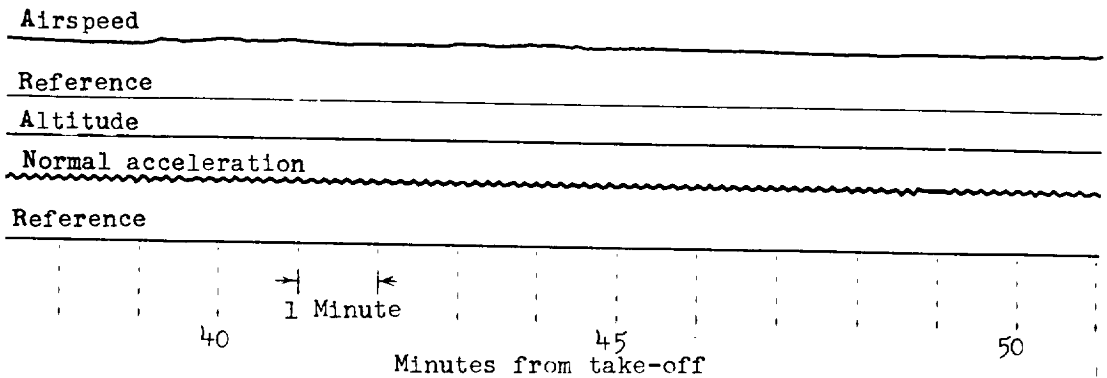


(b) Cruise.

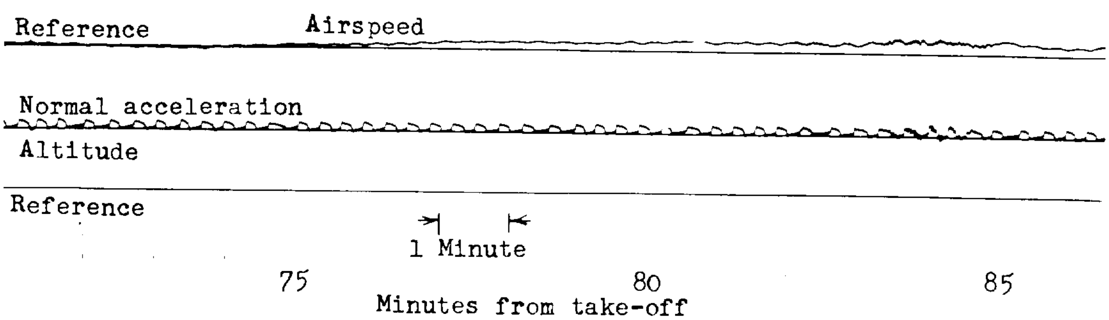


(c) Descent and landing.

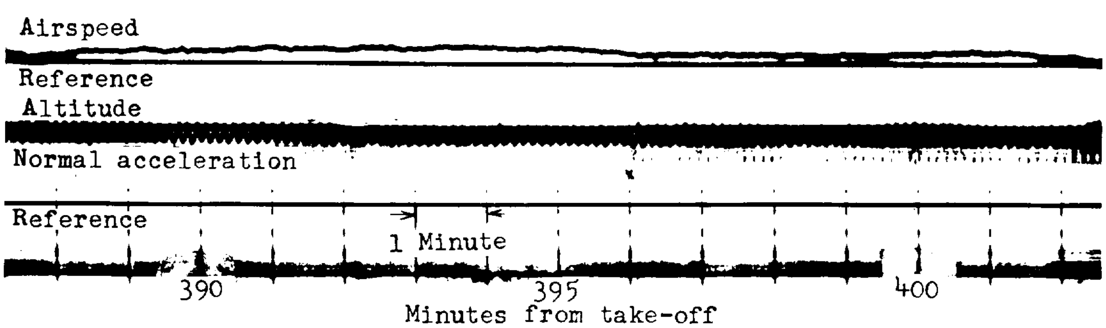
Figure 1.- Sample of VGH record when aircraft not experiencing oscillations.



(a) Constant-amplitude oscillation; $a_n = \pm 0.05g$; P = 10 seconds; V = 310 knots; M = 0.84; h = 31,000 feet.

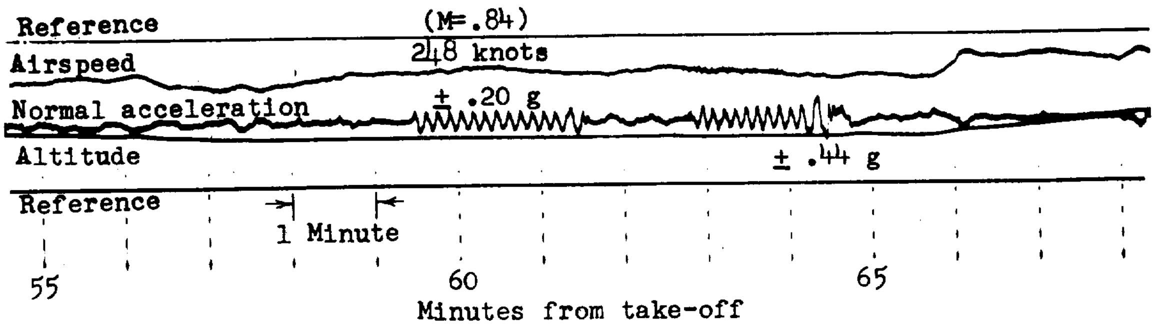


(b) Constant-amplitude oscillation; $a_n = \pm 0.1g$; P = 20 seconds; V = 280 knots (approx.); M = 0.83; h = 35,000 feet.

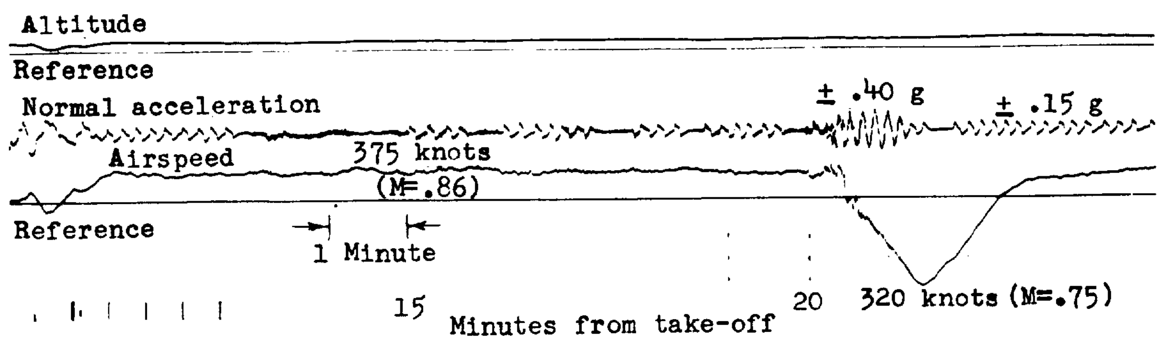


(c) Constant-amplitude oscillation; $a_n = \pm 0.2g$; P = 8 seconds; V = 282 knots (approx.); M = 0.833; h = 35,000 feet.

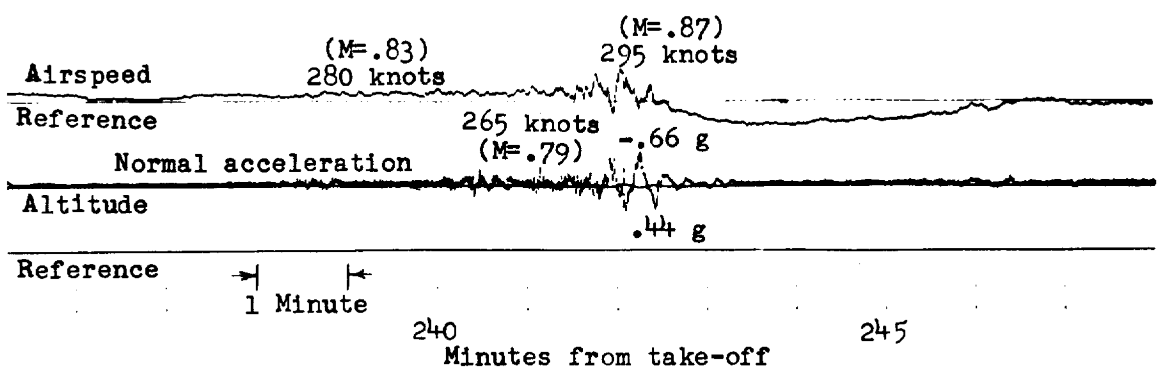
Figure 2.- Samples of oscillations on type I aircraft.



(d) Constant-amplitude oscillation; P = 9 seconds; h = 41,000 feet.

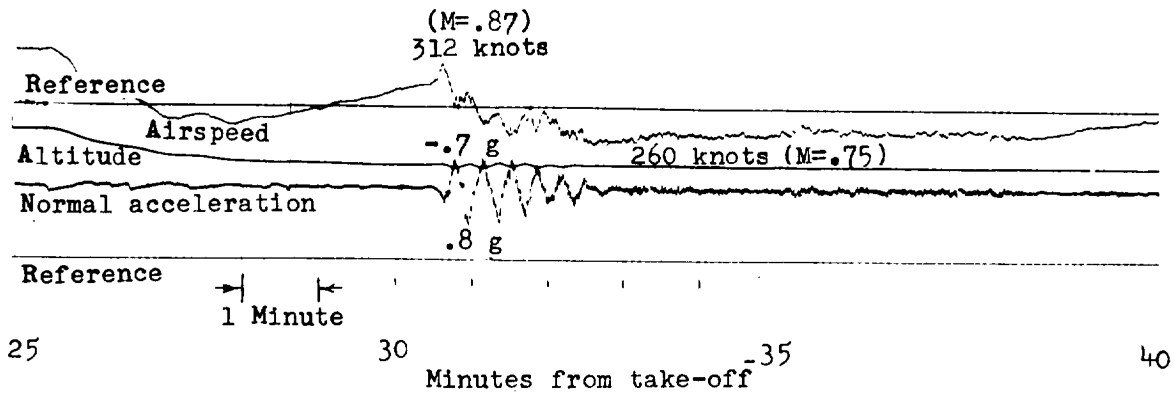


(e) Divergent-convergent oscillation; P = 10 seconds; h = 24,000 feet.

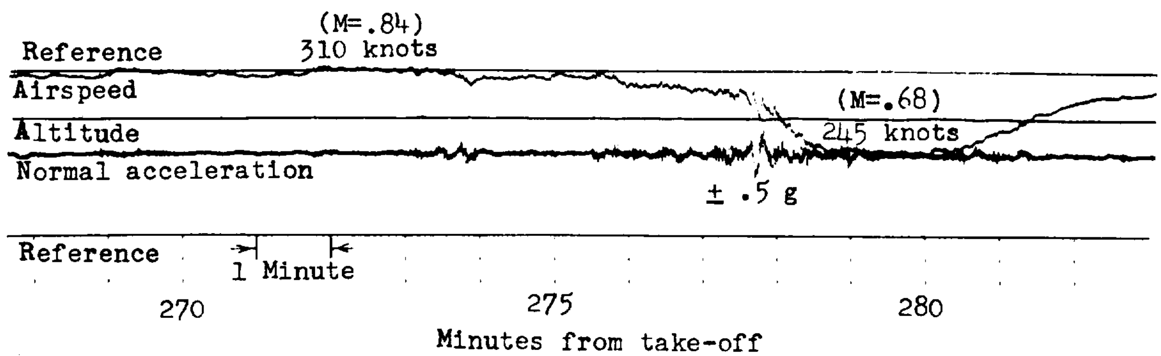


(f) Divergent oscillation; P = 20 seconds (approx.); h = 35,000 ± 180 feet during oscillation.

Figure 2.- Continued.

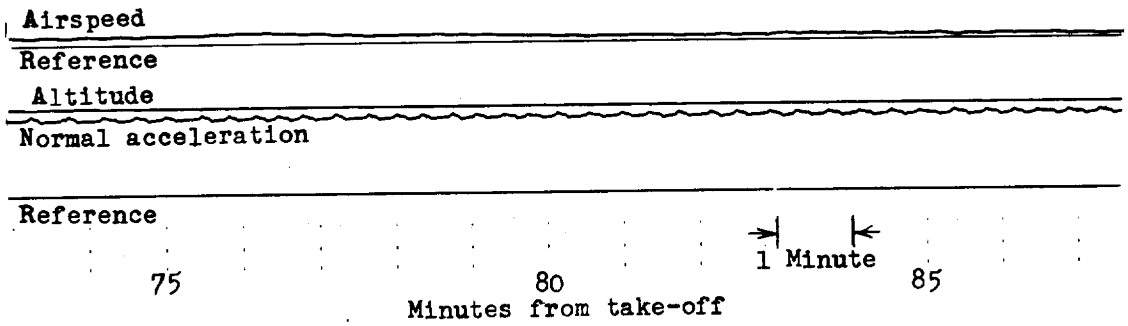


(g) Convergent oscillation; P = 22 seconds (approx.); h = 33,000 ± 315 feet during oscillation.

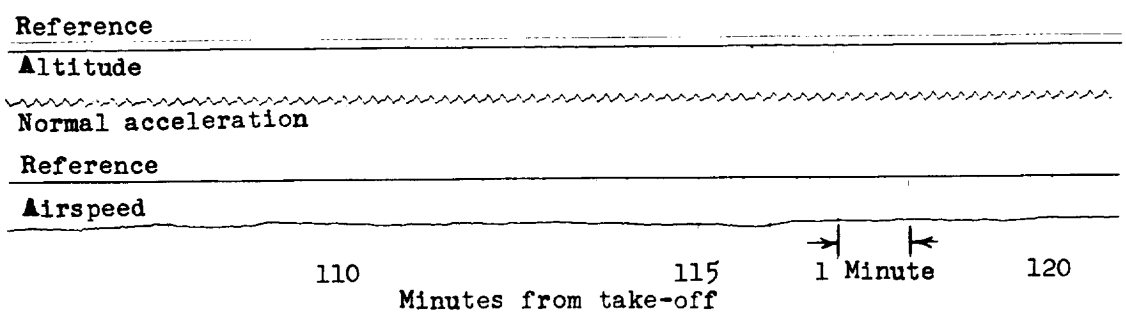


(h) Divergent oscillation; h = 31,000 feet; a_n = ±0.5g.

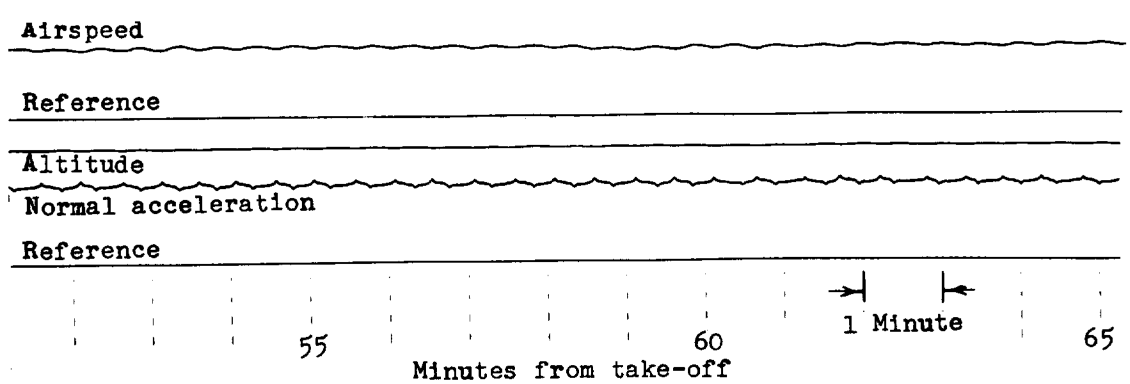
Figure 2.- Concluded.



(a) Constant-amplitude oscillation; $a_n = \pm 0.05g$; $P = 20$ to 27 seconds; $V = 290$ knots; $M = 0.84$; $h = 34{,}000$ feet.

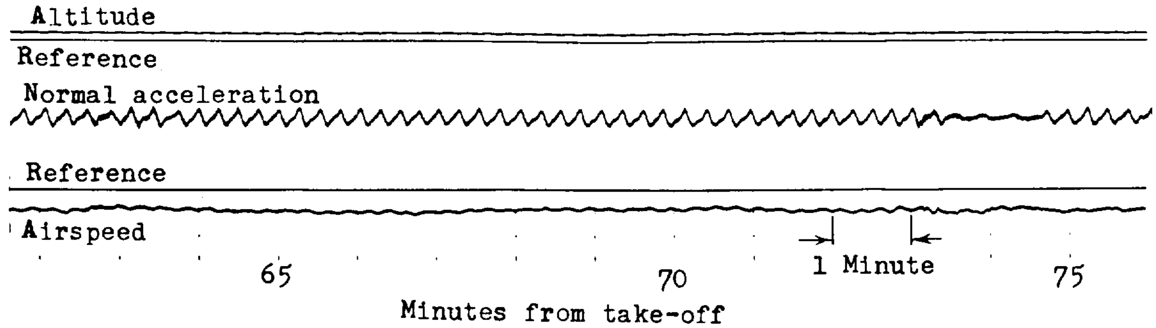


(b) Constant-amplitude oscillation; $a_n = \pm 0.08g$; $P = 12$ seconds; $V = 344$ knots; $M = 0.82$; $h = 25{,}300$ feet.

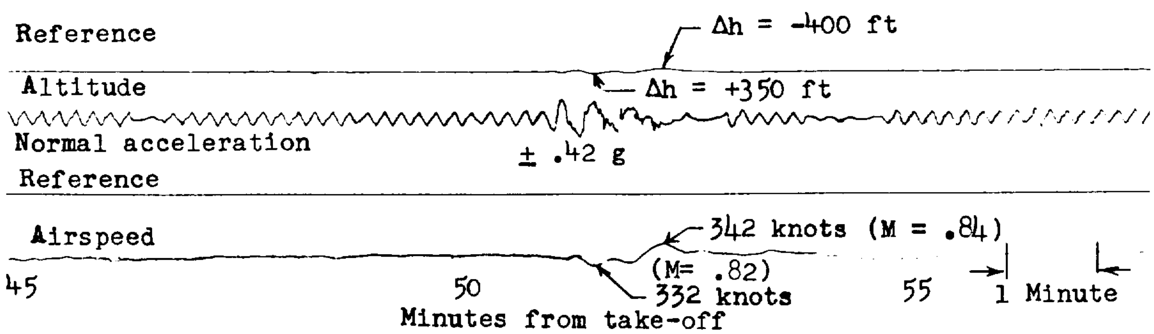


(c) Constant-amplitude oscillation; $a_n = \pm 0.08g$; $P = 25$ to 37 seconds; $V = 320 \pm 1$ knots during oscillation; $M = 0.83$; $h = 29{,}000$ feet.

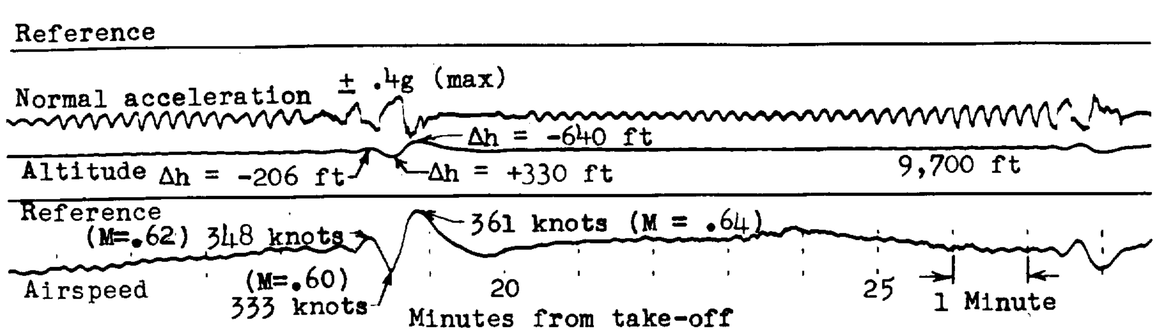
Figure 3.- Samples of oscillations on type II aircraft.



(d) Constant-amplitude oscillation; a_n = ±0.2g; P = 15 seconds; V = 352 knots; M = 0.83; h = 25,000 feet.

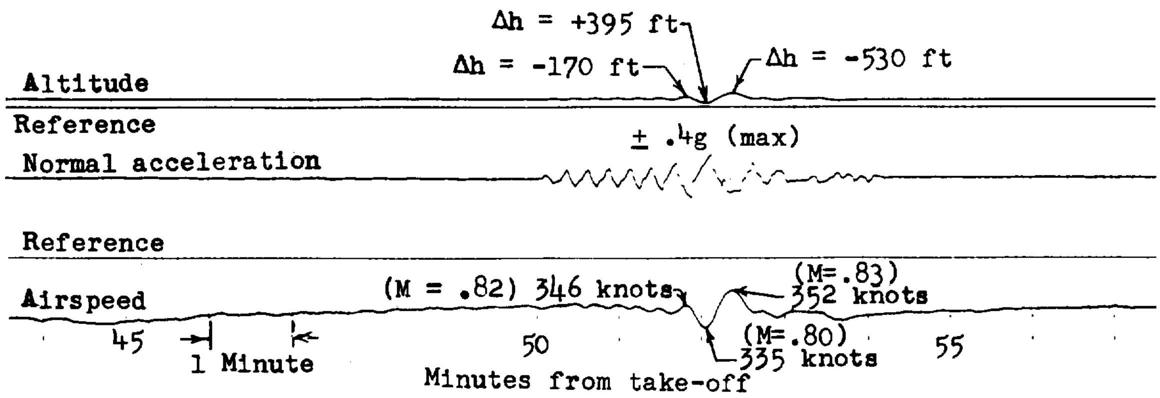


(e) Constant-amplitude oscillation; a_n = ±0.13g; P = 11 seconds; V = 337 knots; M = 0.84; h = 26,700 feet; (departures from stated values noted in figure).

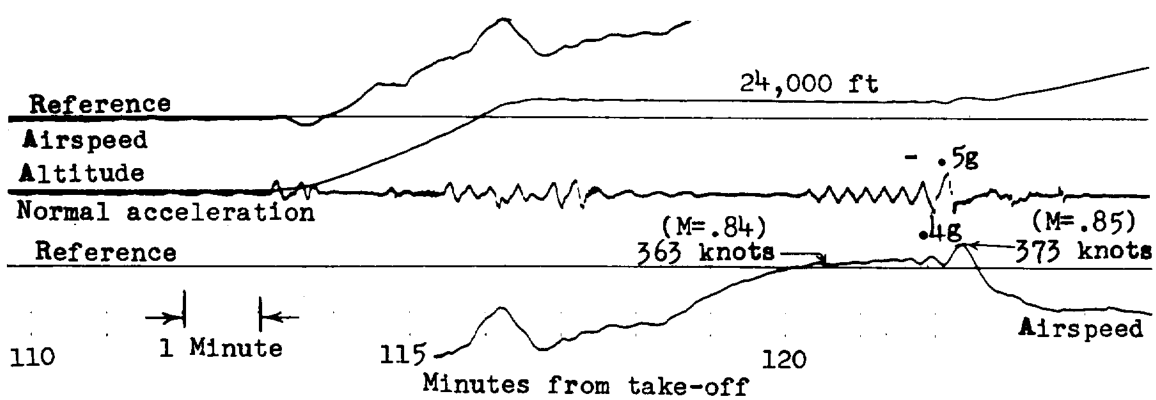


(f) Divergent oscillation; a_n = ±0.08g to ±0.4g; P = 12 seconds.

Figure 3.- Continued.

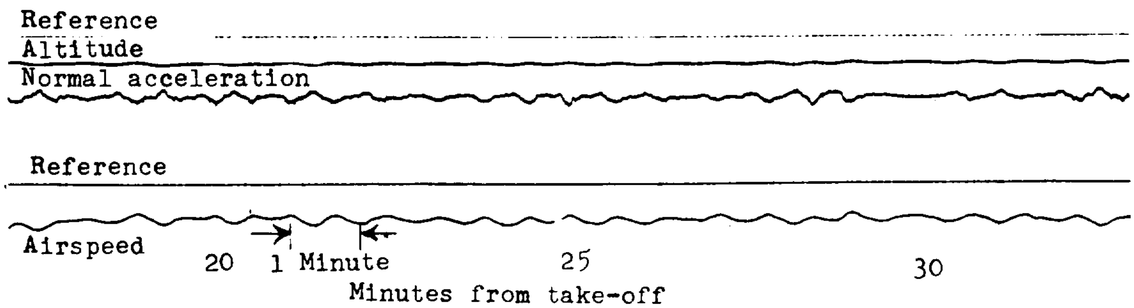


(g) Divergent oscillation; $a_{n,max} = \pm 0.4g$; P = 16 seconds; h = 25,000 feet.

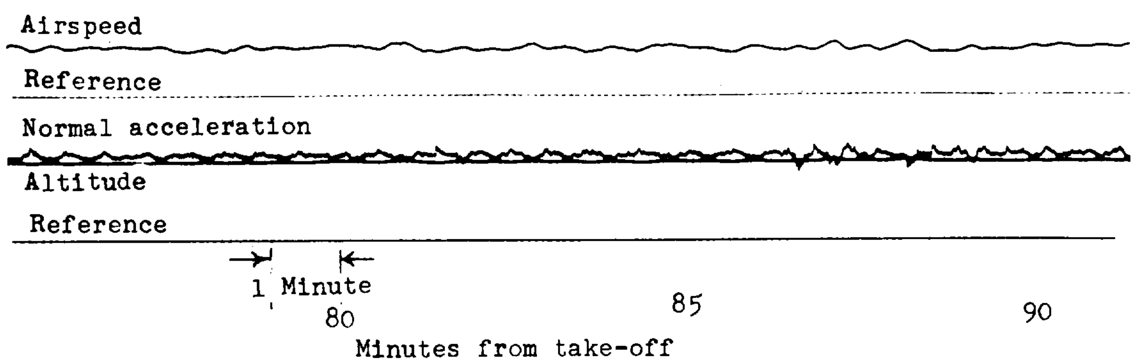


(h) Divergent oscillation; $a_{n,max}$ = 0.4g to -0.5g; P = 17 seconds.

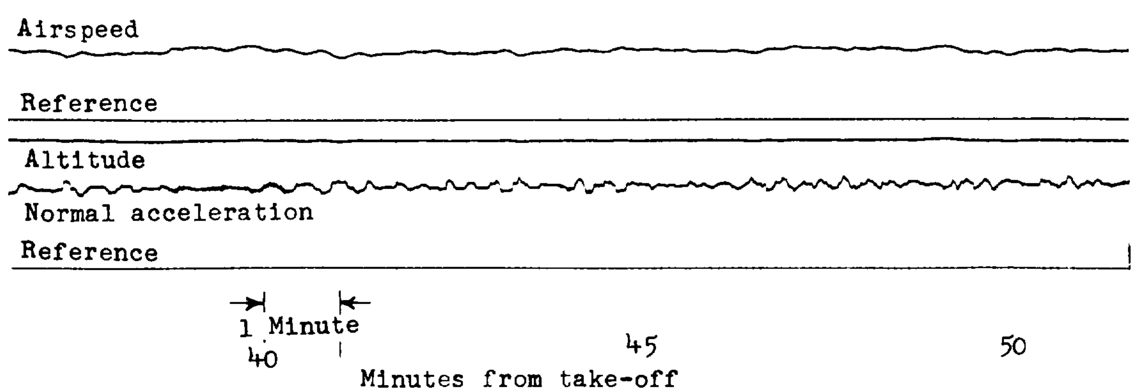
Figure 3.- Concluded.



(a) Irregular oscillation (no autopilot); $a_n = \pm 0.15g$; V = 335 to 338 knots; M = 0.85 to 0.86; h = 28,400 feet.

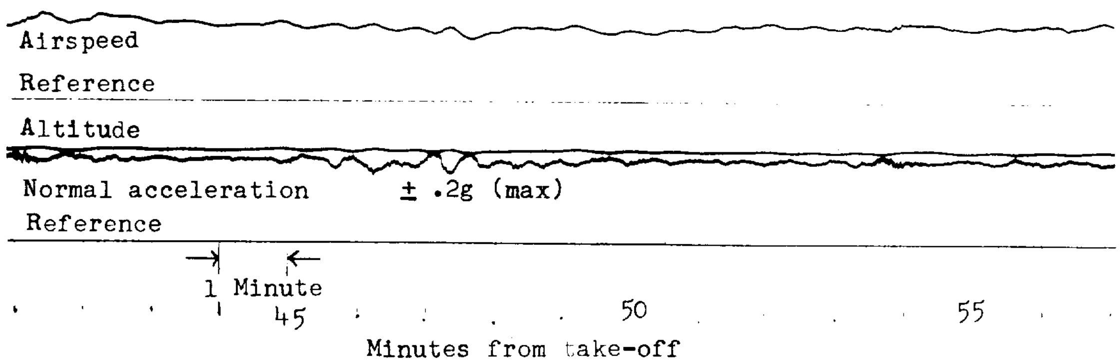


(b) Irregular oscillation (no autopilot); $a_n = \pm 0.1g$; V = 300 knots (approx.); M = 0.86; h = 33,500 feet.

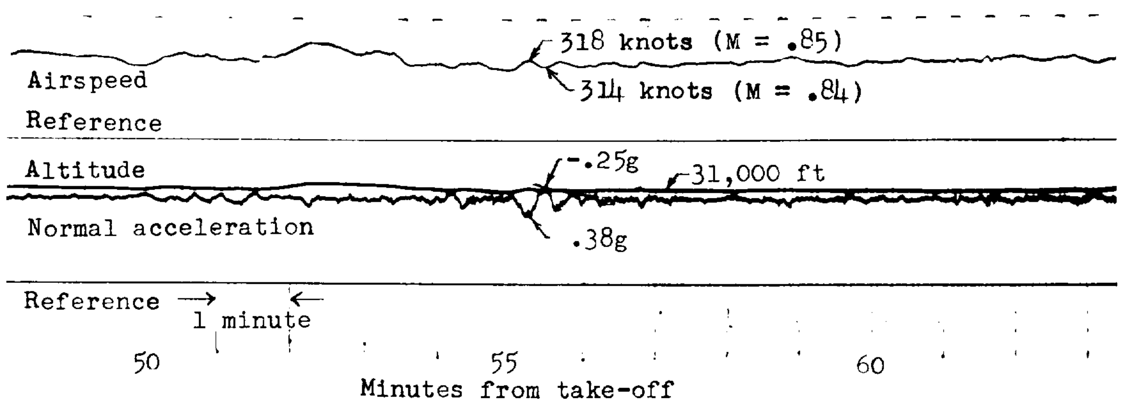


(c) Irregular oscillation (no autopilot); $a_n = \pm 0.1g$; V = 320 knots (approx.); M = 0.81; h = 29,000 feet.

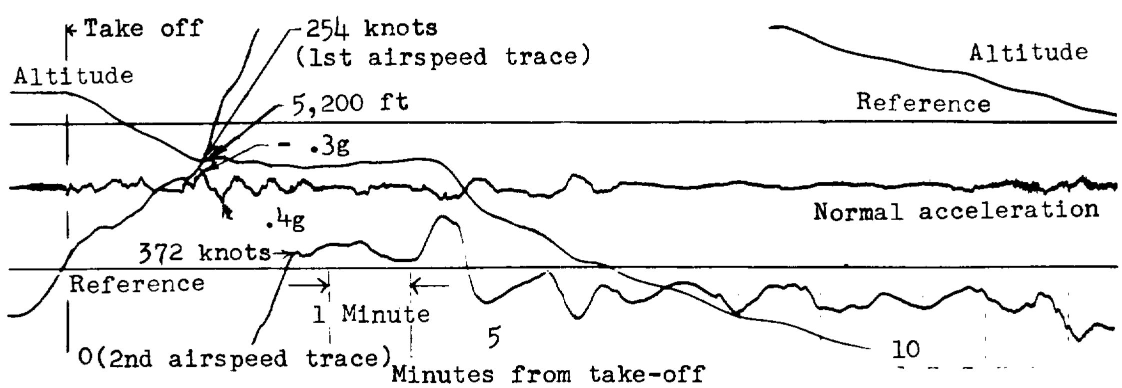
Figure 4.- Samples of oscillations on type III aircraft.



(d) Irregular oscillation (no autopilot); V = 315 knots (approx.); M = 0.85; h = 31,000 feet (approx.).

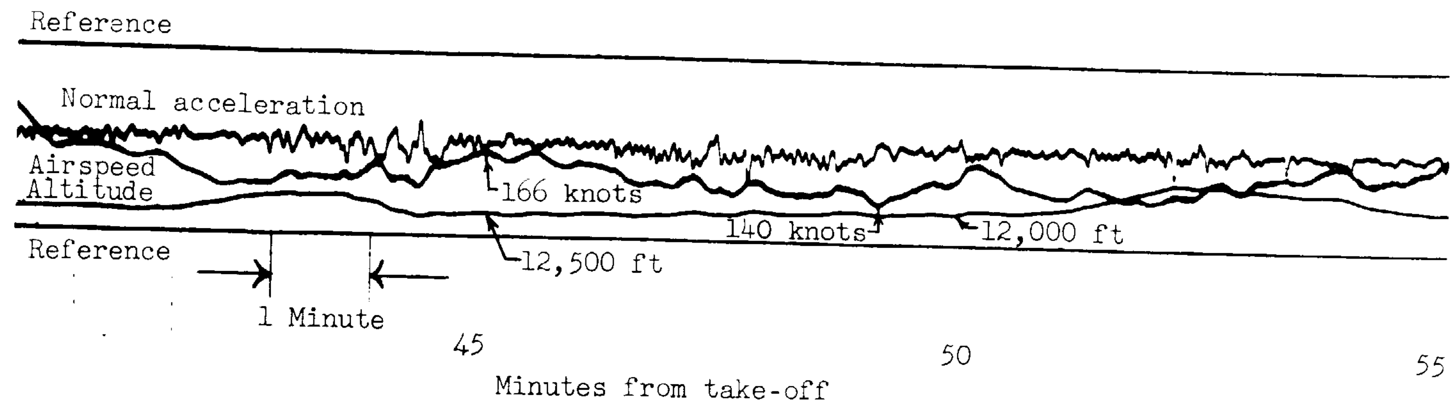


(e) Irregular convergent oscillation (no autopilot).

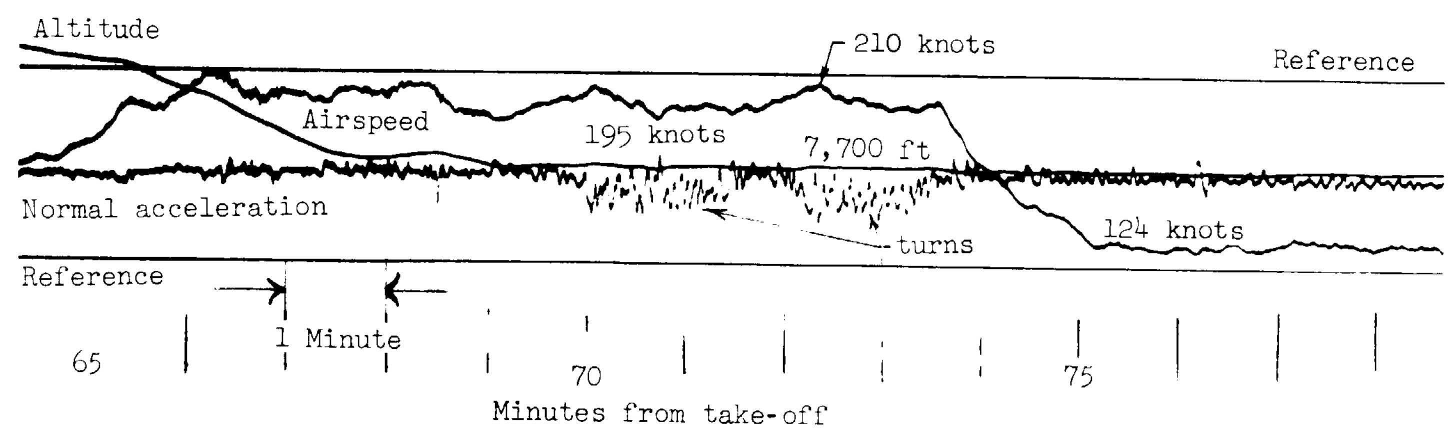


(f) Irregular convergent oscillation (no autopilot).

Figure 4.- Concluded.

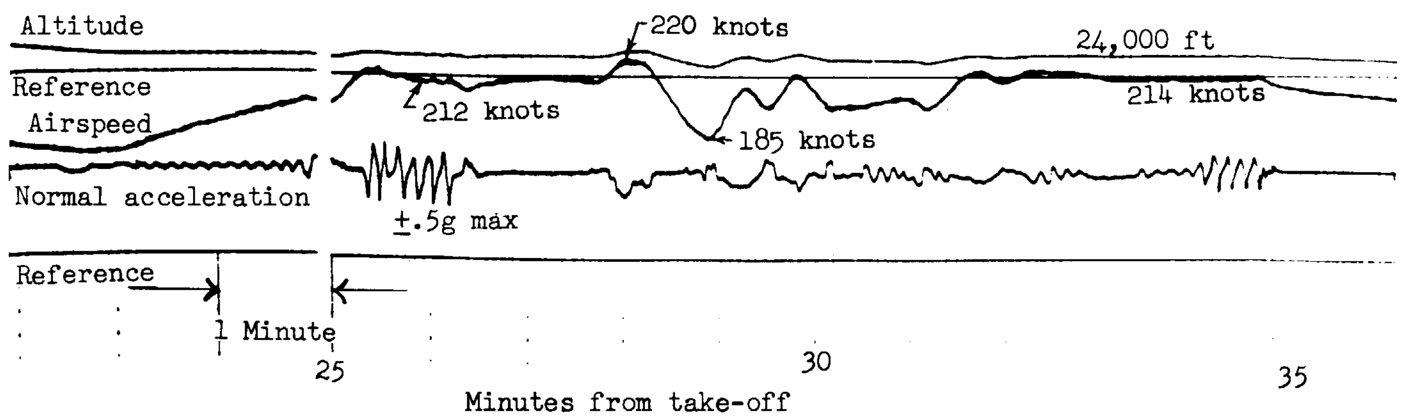


(a) Irregular oscillation (autopilot off); $a_{n,max} = \pm 0.4g$; P = 5 to 6 seconds.

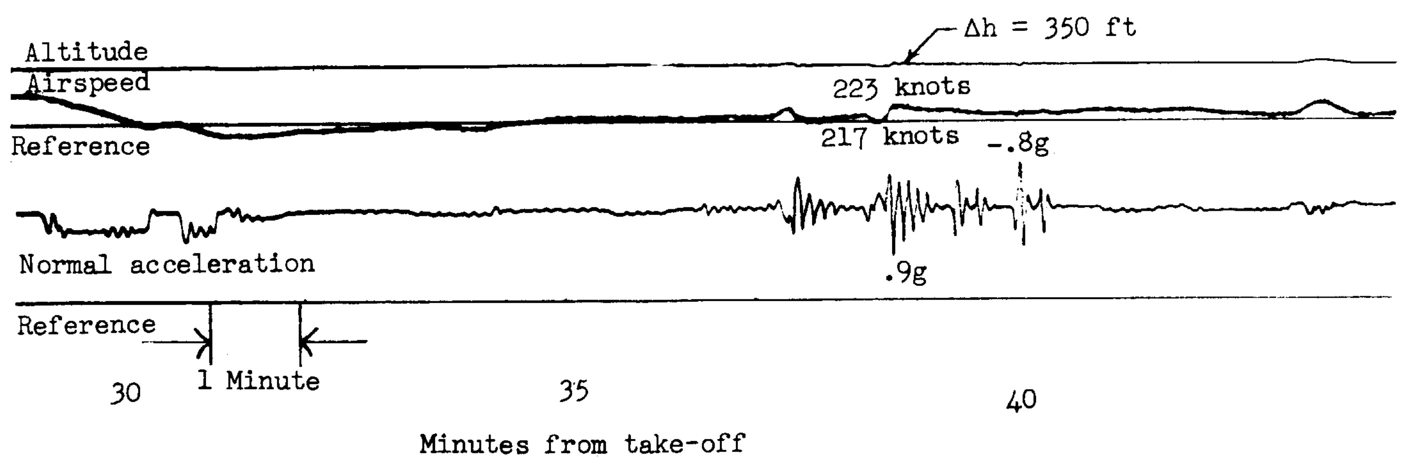


(b) Irregular oscillation during turn maneuver (autopilot off); $a_{n,max} = \pm 0.5g$; P = 9 seconds.

Figure 5.- Samples of oscillations on type IV aircraft.

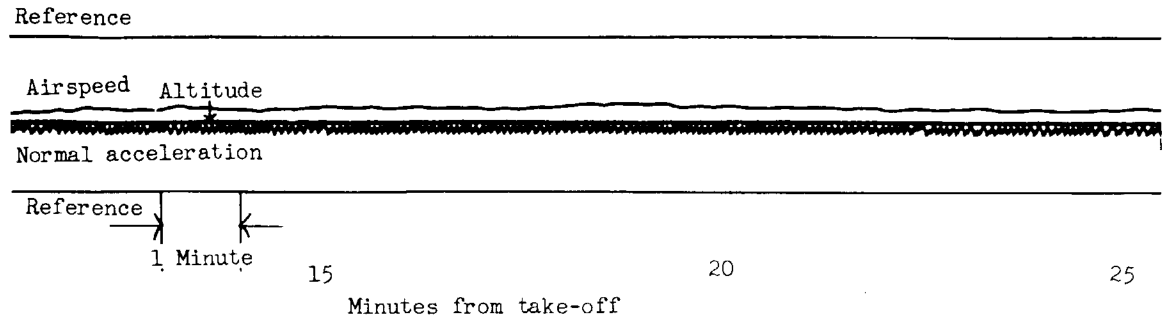


(c) Irregular oscillation; P = 7 to 10 seconds.

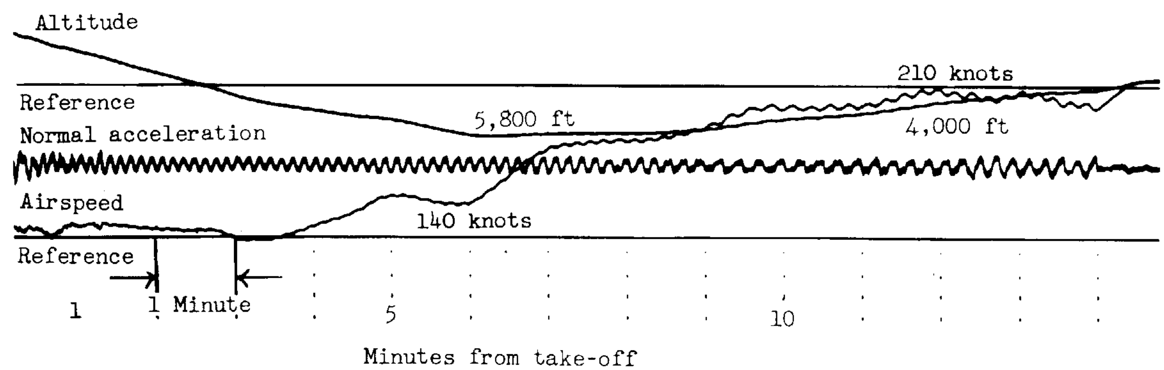


(d) Convergent oscillation; P = 6 to 7 seconds; h = 23,000 feet.

Figure 5.- Concluded.

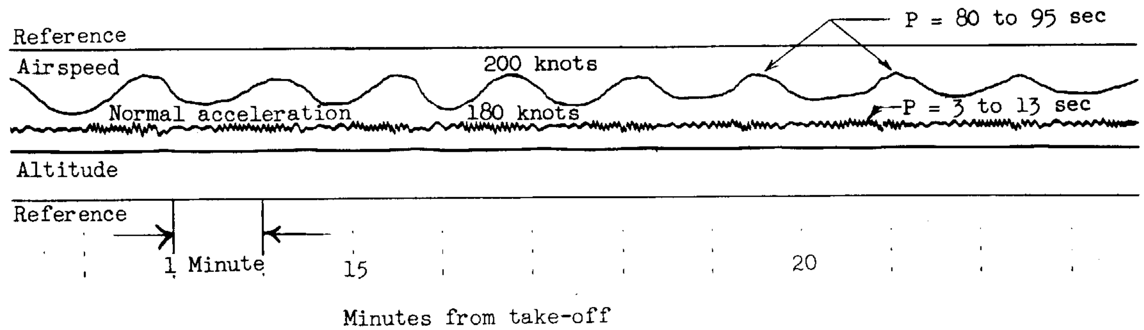


(a) Constant-amplitude oscillation; $a_n = \pm 1g$; $P = 3$ to 6 seconds; $V = 180$ knots (approx.); $h = 7,600$ feet.

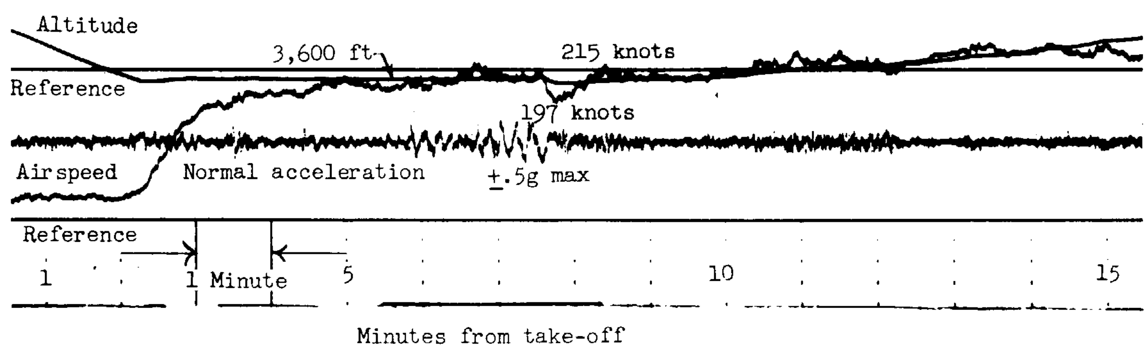


(b) Constant-amplitude oscillation; $a_{n,max} = \pm 0.15g$; $P = 8$ to 16 seconds.

Figure 6.- Sample of oscillations on type V aircraft.

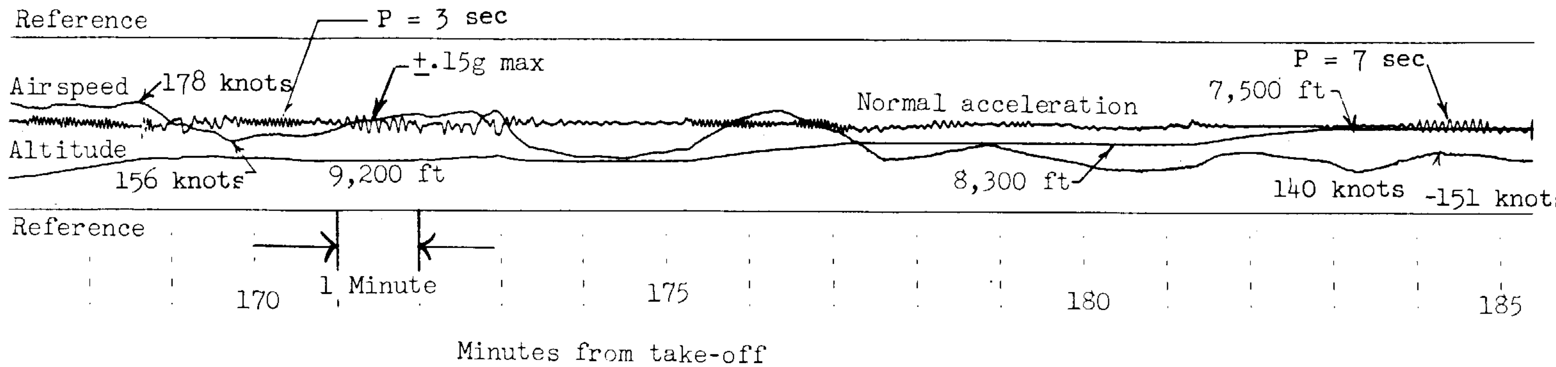


(c) Variable-amplitude, variable-frequency oscillation; $a_{n,max} = \pm 0.1g$; $h = 9{,}300$ feet; $\Delta h = 120$ feet during oscillations.

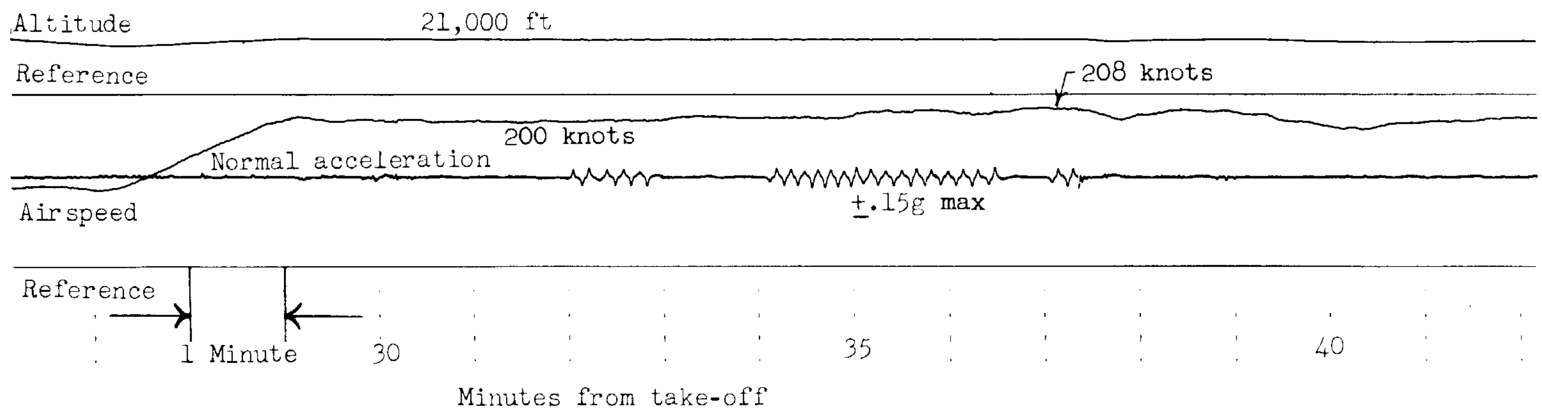


(d) Divergent-convergent oscillation; $P = 14$ seconds; $h = 3{,}600$ feet; $\Delta h = 300$ feet during oscillation.

Figure 6.- Concluded.

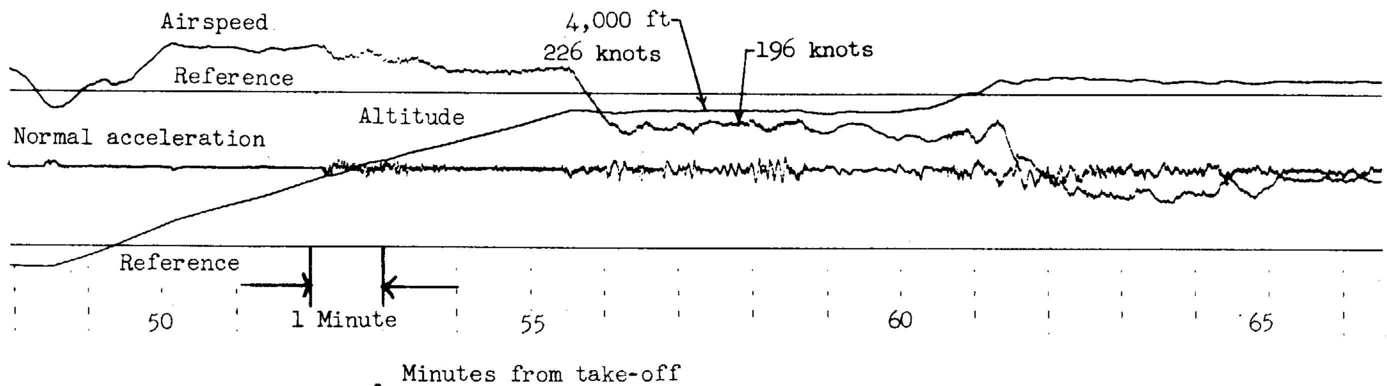


(a) Constant-amplitude oscillation.

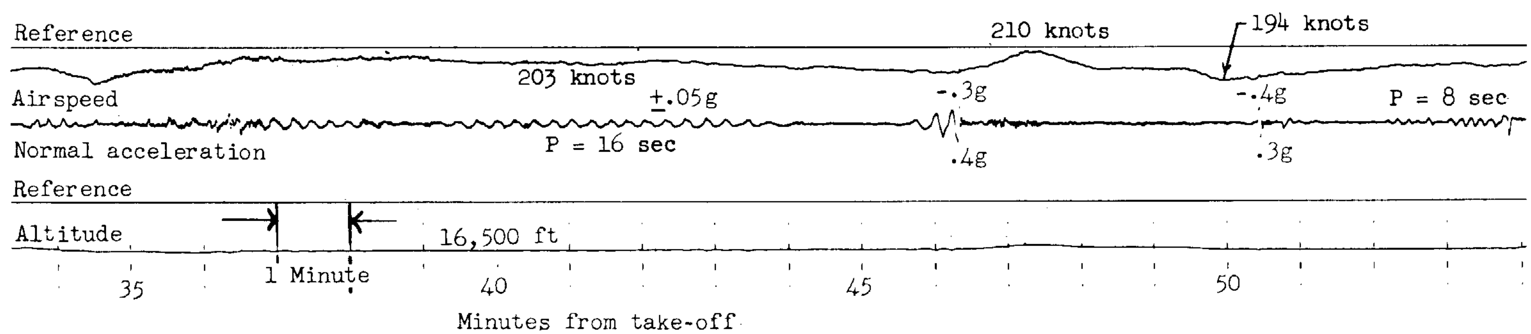


(b) Constant-amplitude oscillation; P = 9 seconds; h = 21,000 feet.

Figure 7.- Samples of oscillations on type VI aircraft.



(c) Random oscillation; $a_{n,max} = \pm 0.25g$; P = 7 seconds (approx.).



(d) Constant-amplitude and divergent oscillation.

Figure 7.- Concluded.

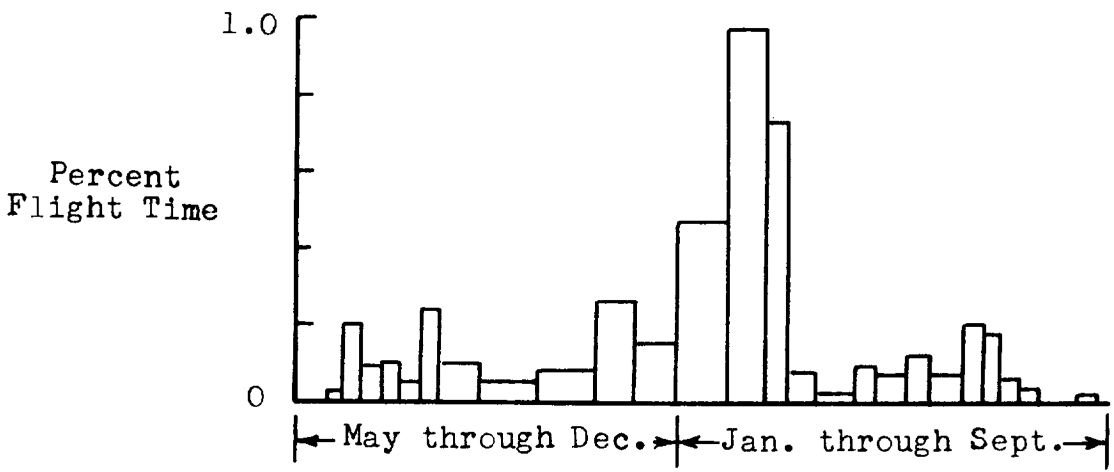


Figure 8.- Effect of maintenance during a 17-month period on the occurrence of in-flight oscillatory accelerations expressed as a percent of flight time.

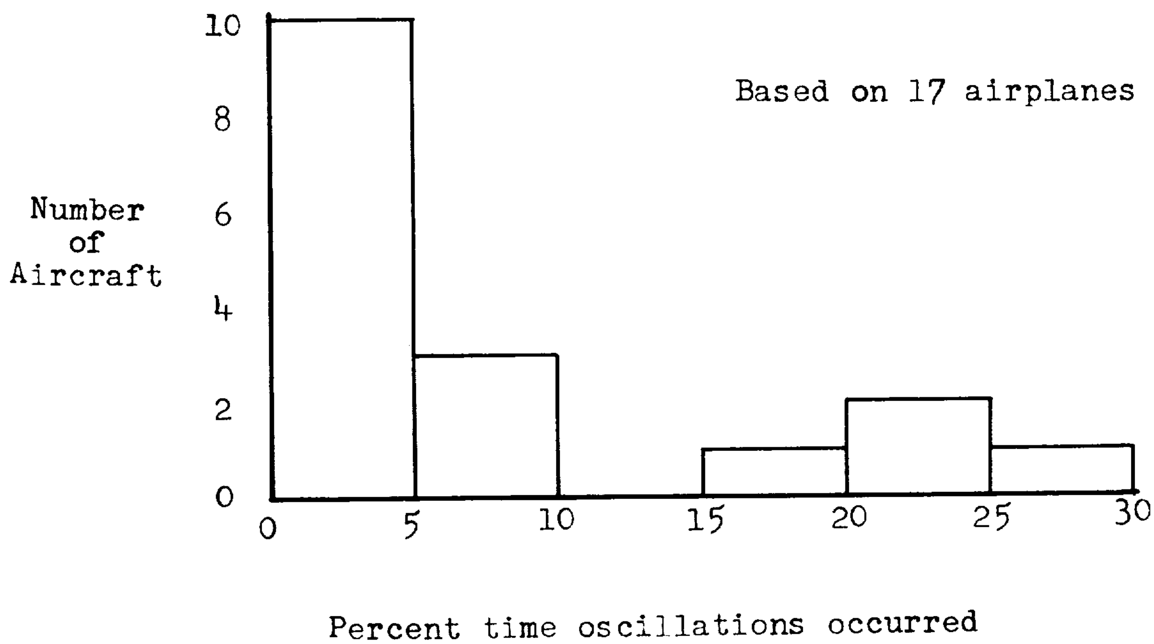


Figure 9.- Distribution of the percent of flight time that oscillations occur for 17 aircraft.

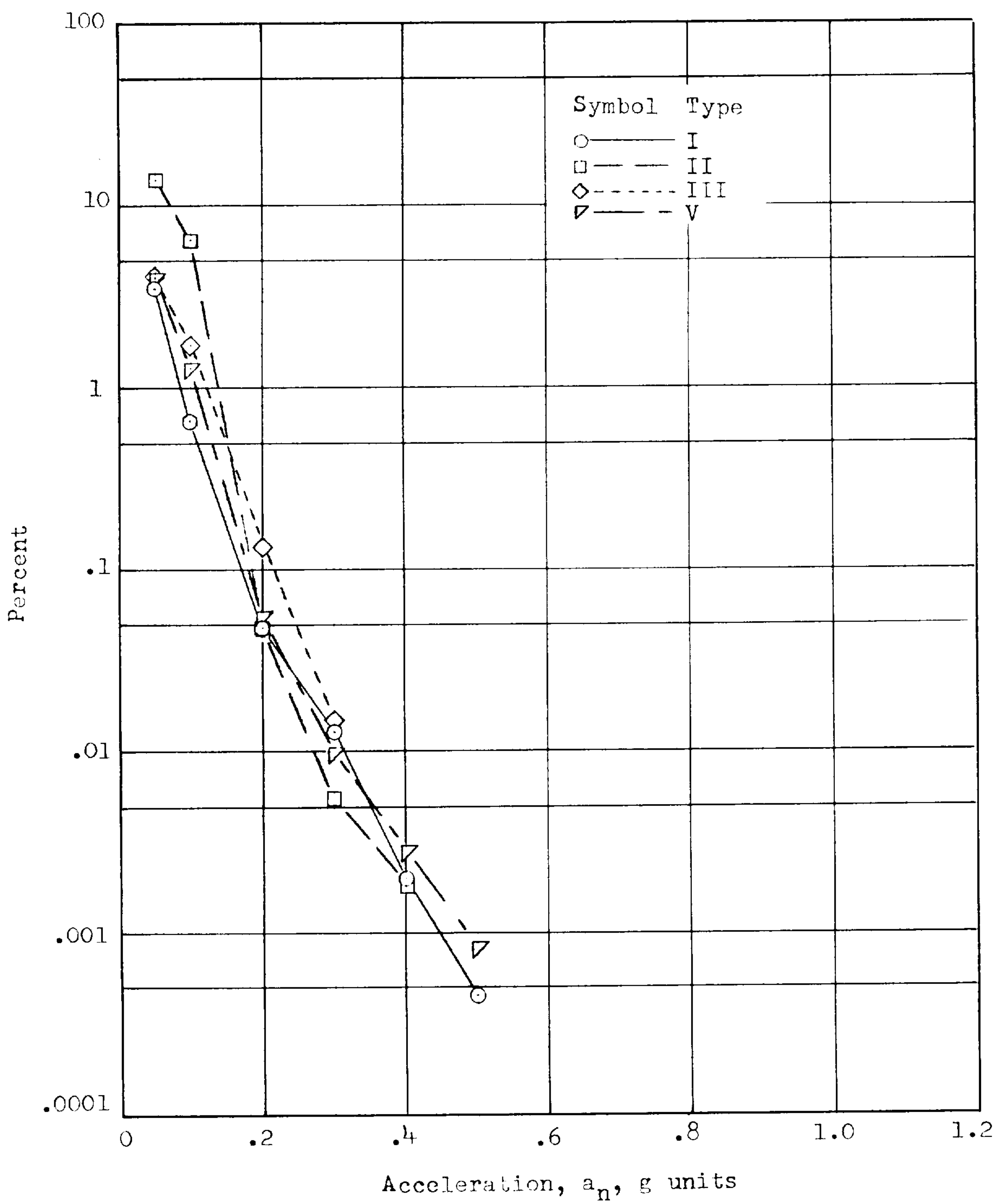


Figure 10.- Percent of time that oscillatory accelerations of various magnitudes were exceeded for several types of transports.

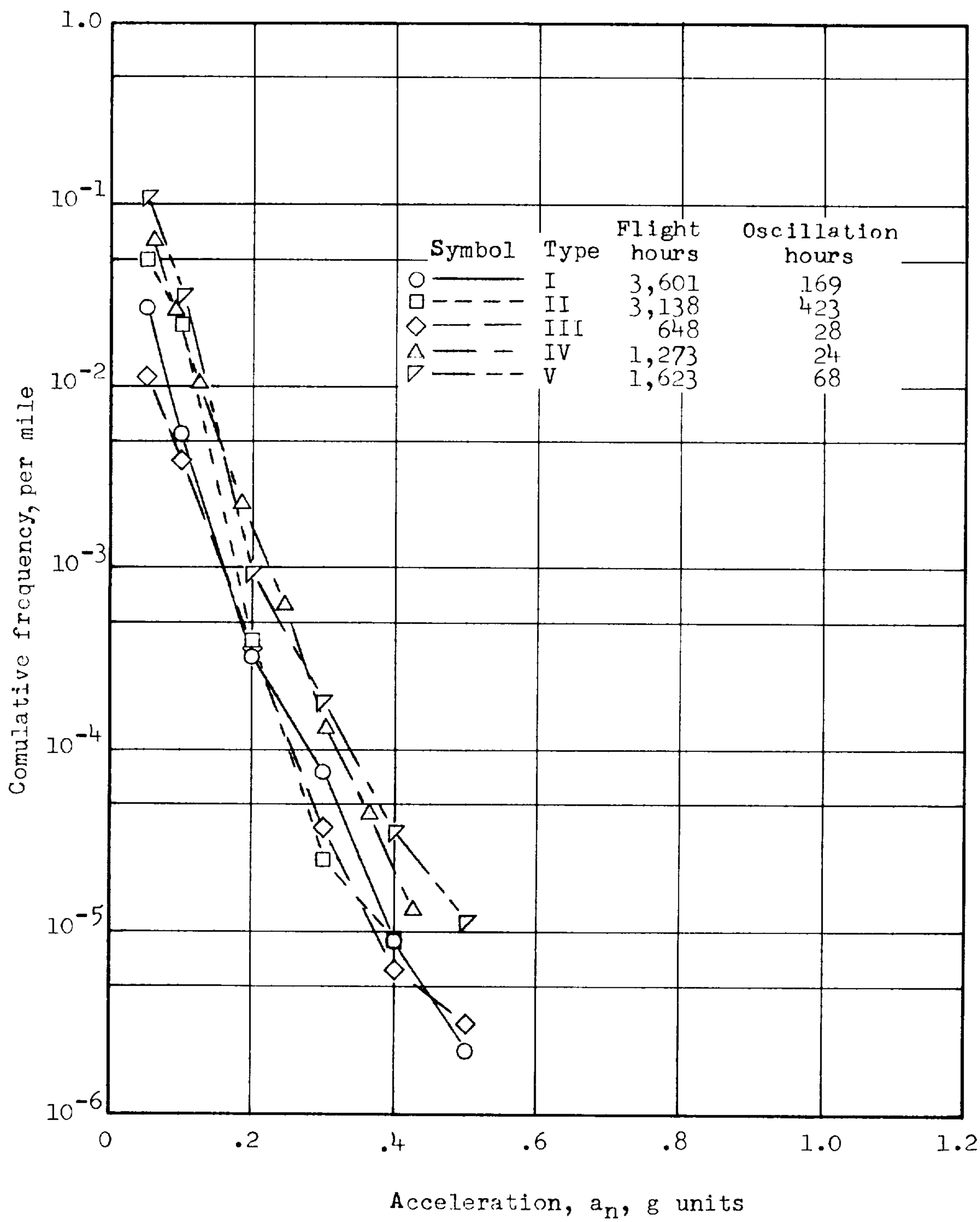


Figure 11.- Cumulative frequency of occurrence of oscillatory accelerations for several types of transports.

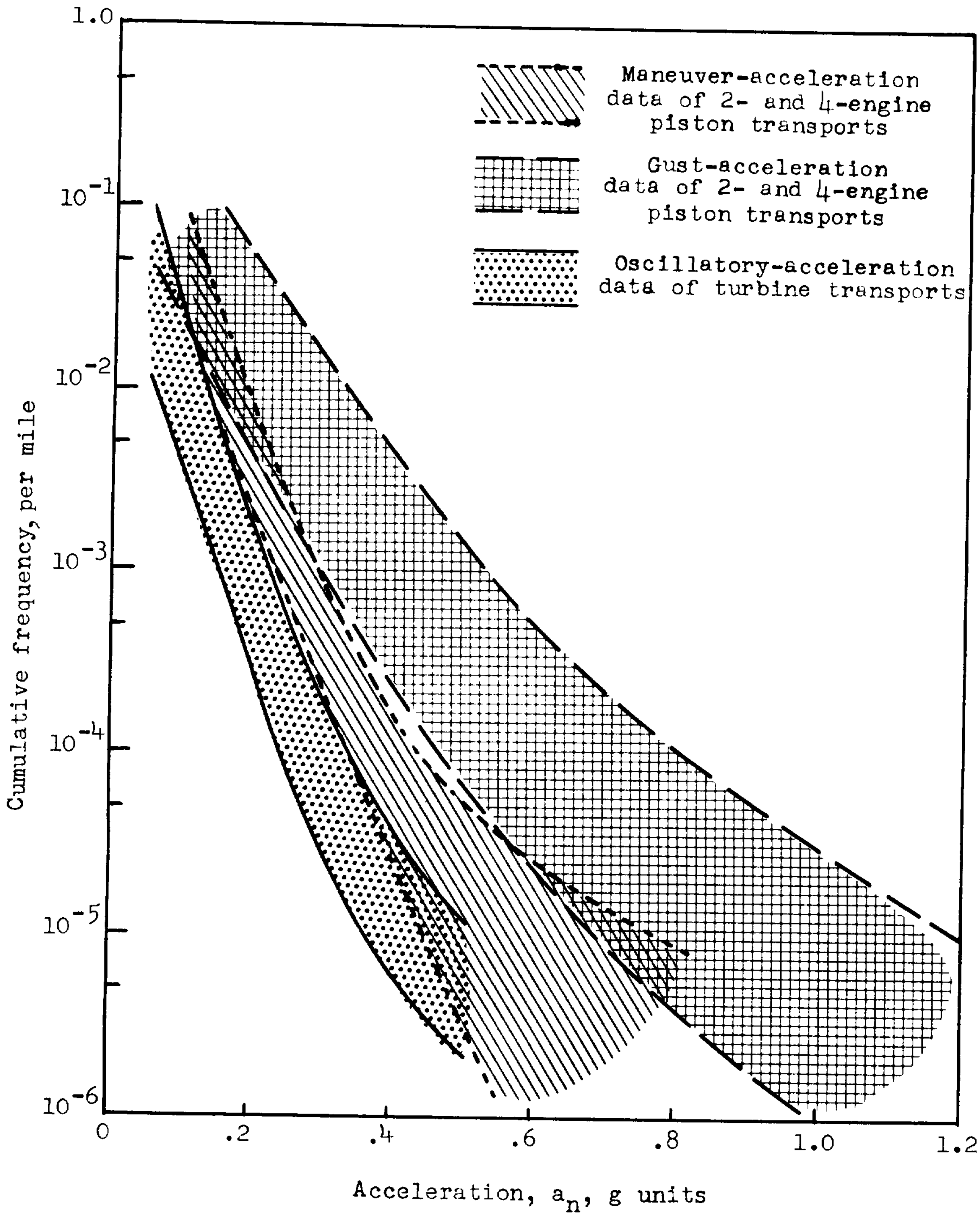


Figure 12.- Cumulative frequency of occurrence of oscillatory acceleration for several types of turbine transports compared with maneuver- and gust-acceleration experience for piston-engine aircraft.

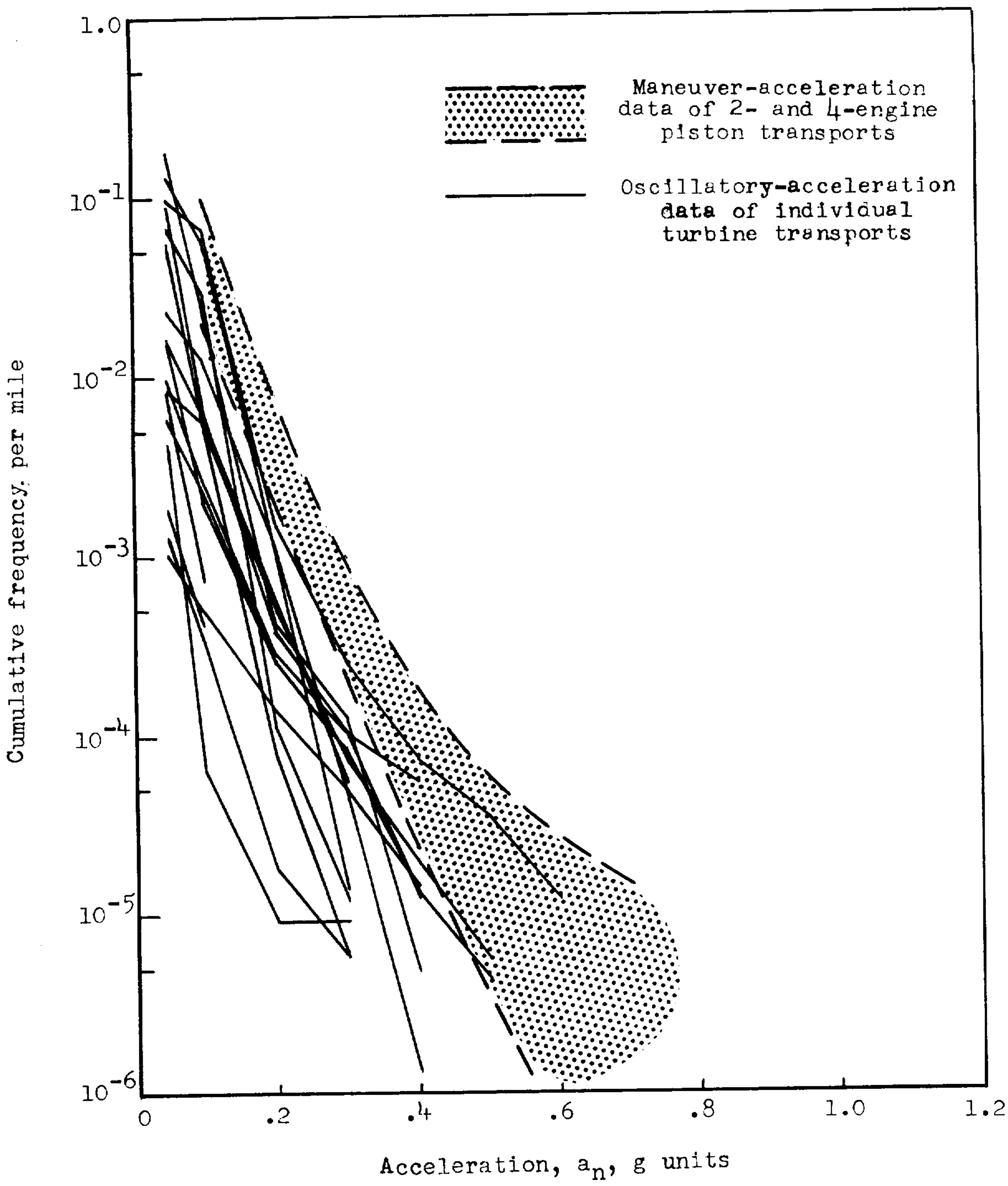


Figure 13.- Cumulative frequency of occurrence of oscillatory accelerations for 16 individual turbine aircraft compared with maneuver accelerations experienced by piston-engine aircraft.

VI. SOME INFORMATION ON THE GUST AND MANEUVER LOADS EXPERIENCED BY TURBINE-POWERED TRANSPORTS

By Paul A. Hunter

SUMMARY

Data on the magnitude and frequency of occurrence of maneuver and gust accelerations and gust velocities experienced during routine commercial operations of two types of turbojet and three types of turboprop airplanes are presented.

INTRODUCTION

The VGH records collected on turbine-powered commercial transports are being used to obtain data on the maneuver and gust loads experienced during routine operations. In the past, such data have proven useful in providing a basis for assessing the adequacy of the loading spectrum used in design, in formulating improved structural and airspeed design requirements, and in providing background information for use in design of more advanced types of airplanes.

The initial VGH sample of loads data was obtained on a four-engine turboprop airplane and is reported in reference 1. Additional data have been collected on two other types of turboprop airplanes and on two types of turbojet airplanes. Although the data samples for some of the operations are still quite limited, it was thought desirable to publish the preliminary results at this time. In this report, therefore, the available data on gust and maneuver loads and gust velocity are summarized.

SYMBOLS

A aspect ratio

a_n increment of normal acceleration, g units

g acceleration due to gravity, 32.2 ft/sec^2

M Mach number

m lift-curve slope, per radian

m_c calculated lift-curve slope, per radian

S wing area, sq ft

U_{de} derived gust velocity, $\frac{2Wa_n}{K_g \rho_o V_e m S}$, ft/sec

V_e equivalent airspeed, ft/sec

W airplane gross weight, lb

Λ wing sweep angle, deg

ρ_o air density at sea level, slugs/cu ft

K_g gust factor (ref. 2)

EVALUATION OF RECORDS

The VGH records were evaluated essentially in accordance with the procedures discussed in reference 3 to obtain the frequency distributions of: (1) maneuver acceleration experienced during routine operational passenger-carrying flights and during airplane-check or pilot-training flights, (2) gust accelerations, and (3) derived gust velocities.

The gust velocities were computed by using the gust equation given in reference 2 in conjunction with the simultaneous values of peak acceleration, airspeed, and altitude determined from the records. For the turboprop airplanes, average operating weights were used in computing the gust velocities; whereas, for the turbojets, weights appropriate to each particular rough-air encounter were determined from flight logs and were used in computing the gust velocities. The lift-curve slopes used in the gust equation are indicated in figure 1 for each airplane type. The slopes for swept-wing, turbojet airplanes, types I and II, were computed by the equation:

$$m_c = \frac{6A \cos \Lambda}{A + 2 \cos^2 \Lambda}\left(\frac{A + 2 \cos}{A\sqrt{1 - M^2 \cos^2 \Lambda} + 2 \cos \Lambda}\right)$$

which takes into account wing sweep and Mach number effects. The background for the formula may be found in references 4 and 5. The wing lift-curve slopes for type IV, a straight-wing turboprop, were obtained from the manufacturer. Slopes for types V and VI, low-speed, low-altitude, straight-wing turboprops, were calculated by the equation: $m_c = \frac{6A}{A + 2}$.

SIZE OF DATA SAMPLES

The sizes of the VGH record samples from which the present data were obtained are shown in table I. As shown in the table, data samples ranging from about 600 to 1,800 hours were available for airplanes I-A, IV-A, V-A, and VI-A. The data sample for type VI-A aircraft was taken from reference 1. Based on past experience, these samples are thought to be adequate to give a good definition of the acceleration experience. The sample for type II-B covers only 85 flight hours, however, and the results for this type of airplane must be considered as having relatively low statistical reliability.

RESULTS AND DISCUSSION

Operational Maneuver Accelerations

The maneuver accelerations experienced during the operational passenger-carrying flights are presented in figure 2 in terms of the cumulative frequency of occurrence per mile of flight of given acceleration values. For comparison, the upper and lower limits of corresponding results taken from reference 3 for operations of four-engine piston transports are also shown in the figure.

Consideration of figure 2 shows that variations on the order of 10 to 1 exist in the frequency of occurrence of given values of acceleration for the different turbine airplanes. These differences in maneuver-acceleration experiences are not due solely to differences in airplanes, but rather reflect to a large extent the demands of the particular operation, that is, length of flights involved, air-traffic control procedures, and operational techniques of the various operators involved. In addition, some of the differences may be ascribed to low statistical reliability. For example, it may be noted that the more severe maneuver distributions are associated with the operations having the smaller data samples.

Comparison of the results in figure 2 for the turbine-powered transports with the results for piston-engine transports indicates that, taken as a whole, the turbine transports are maneuvered somewhat more frequently than were the piston-engine transports. Larger data samples than are currently available, however, will be required to determine the reliability of the present indications of an increase in operational maneuvers.

Check-Flight Maneuver Accelerations

The maneuver accelerations experienced during the airplane-check and pilot-training flights are presented in figure 3 in terms of the cumulative frequency of occurrence per mile of overall flight of given values of acceleration. For comparison, the upper and lower limits of corresponding results taken from reference 3 for operations of four-engine piston transports are also shown in the figure.

Figure 3 indicates that differences as large as 100 to 1 exist among the frequencies at which the various turbine transports experience a given value of maneuver acceleration during check flights. As was indicated previously for the operational maneuvers, the differences shown in figure 3 between the frequency of occurrence of check-flight maneuvers do not reflect solely differences in airplane types. Rather, the differences shown reflect operator requirements in regard to airplane and pilot check flights and training flights. In this regard, some of the results shown in figure 3 (particularly those for airplane II) represent operations within a few months after the airplanes were received by the operators. Thus, the pilot-training requirements may have been relatively high during this period and will decrease with continued operational use. In this case, the results shown in figure 3 would be expected to decrease as the operational time increased.

Comparison of the present results in figure 3 with those for the piston-engine airplanes shows that, from the overall viewpoint, the acceleration experiences for the check flights tend to be along the upper boundary of the piston-engine experience. For the turbine operations, however, the results must in some cases be considered as being preliminary and the comparisons shown in figure 3 may change appreciably as the data samples are increased.

Gust Accelerations

The gust-acceleration data are summarized in figure 4 in terms of the cumulative frequency of occurrence per mile of flight of given values of acceleration. For comparison, the upper and lower limits of VGH gust data collected on four-engine piston transports (ref. 3) are also shown in the figure. The differences between the gust-acceleration frequencies for the various operations shown are due to factors such as airplane characteristics (wing loading, speed, and lift-curve slopes), differences in turbulence environment, and type of operation (feeder-line, short haul, or long haul). Except for airplane V, the acceleration histories shown in figure 4 for the turbine transports are comparable to previous results obtained on four-engine piston transports. The relatively high frequency of occurrence of gust accelerations for airplane V is due primarily to the fact that this was a feeder-line operation, involving short (25 minutes) flights with most of the time spent at low altitude where turbulence is most prevalent.

Gust Velocities

The cumulative-frequency distributions of derived gust velocities per mile of flight are given in figure 5 for the five turbine-powered transports. The upper and lower limits of corresponding results from reference 3 for four-engine piston transports are also shown in the figure for comparative purposes. For the various turbine transports, differences on the order of 50 to 1 are noted in the frequency of occurrence of given values of gust velocity. These differences in gust experience primarily are due to differences in operating altitudes, and hence different gust environments, for the several airplanes. For example, the airplane with the highest gust experience (airplane V) had the lowest average operating altitude; whereas the airplane with the lowest gust experience (airplane I) had the highest average operating altitude. In general, the gust histories for the turbine transports are not significantly different from those for the four-engine piston airplanes.

CONCLUDING REMARKS

Analysis of VGH records collected on three types of turboprop and two types of turbojet transports has provided information on the maneuvers experienced during routine operational flights and during airplane and pilot check flights, the gust accelerations experienced, and the gust velocities encountered. From the overall viewpoint, the results indicate that the turbine transports are maneuvered somewhat more frequently than were four-engine piston transports. In general, the gust-acceleration and gust-velocity histories for the turbine airplanes do not appear to be significantly different from the histories recorded on piston-engine airplanes.

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2. Pratt, Kermit G., and Walker, Walter G.: A Revised Gust-Load Formula and a Re-Evaluation of V-G Data Taken on Civil Transport Airplanes From 1933 to 1950. NACA Rep. 1206, 1954. (Supersedes NACA TN's 2964 by Kermit G. Pratt and 3041 by Walter G. Walker.)

3. Walker, Walter G., and Copp, Martin R.: Summary of VGH and V-G Data Obtained From Piston-Engine Transport Airplanes From 1947 to 1958. NASA TN D-29, 1959.

4. Fisher, Lewis R.: Approximate Corrections for the Effects of Compressibility on the Subsonic Stability Derivatives of Swept Wings. NACA TN 1854, 1949.

5. Funk, Jack, and Mickleboro, Harry C.: A Comparison of Gust Loads Measured in Flight on a Swept-Wing Airplane and an Unswept-Wing Airplane. NACA RM L52L02, 1952.

TABLE I.- SIZES OF VGH DATA SAMPLES EVALUATED FOR MANEUVER AND GUST ACCELERATIONS

Airplane designation (type-series)	Flight hours of VGH data		
	Operational flights	Check flights	Total
I-A	1,155	80	1,235
II-B	85	15	100
IV-A	1,322	35	1,357
V-A	623	20	643
VI-A[a]	1,838	19	1,857

[a]Reported in reference 1.

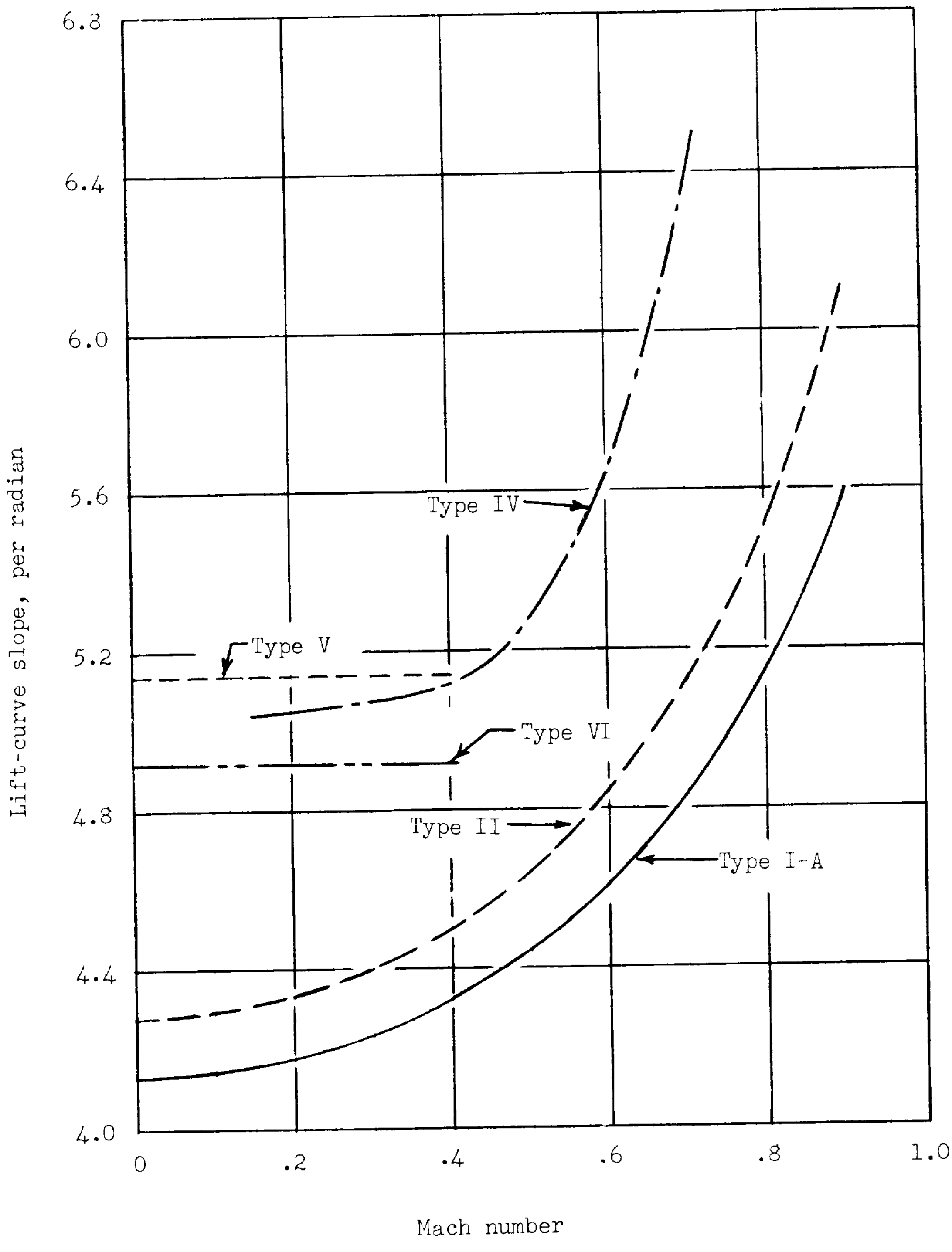


Figure 1.- Lift-curve slopes used in calculating U_{de}.

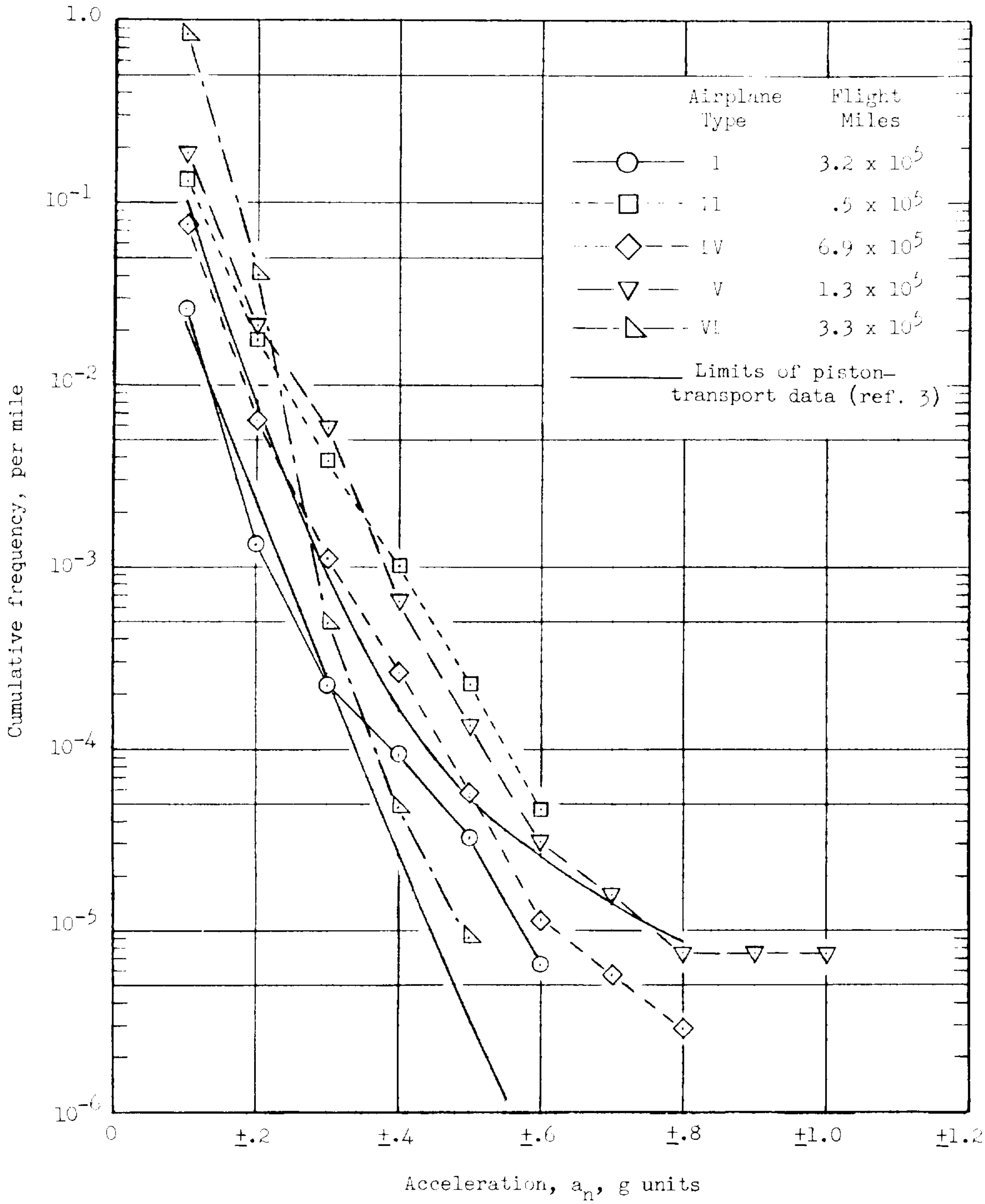


Figure 2.- Comparison of frequency of occurrence per mile of flight of operational maneuver accelerations for several types of airplanes.

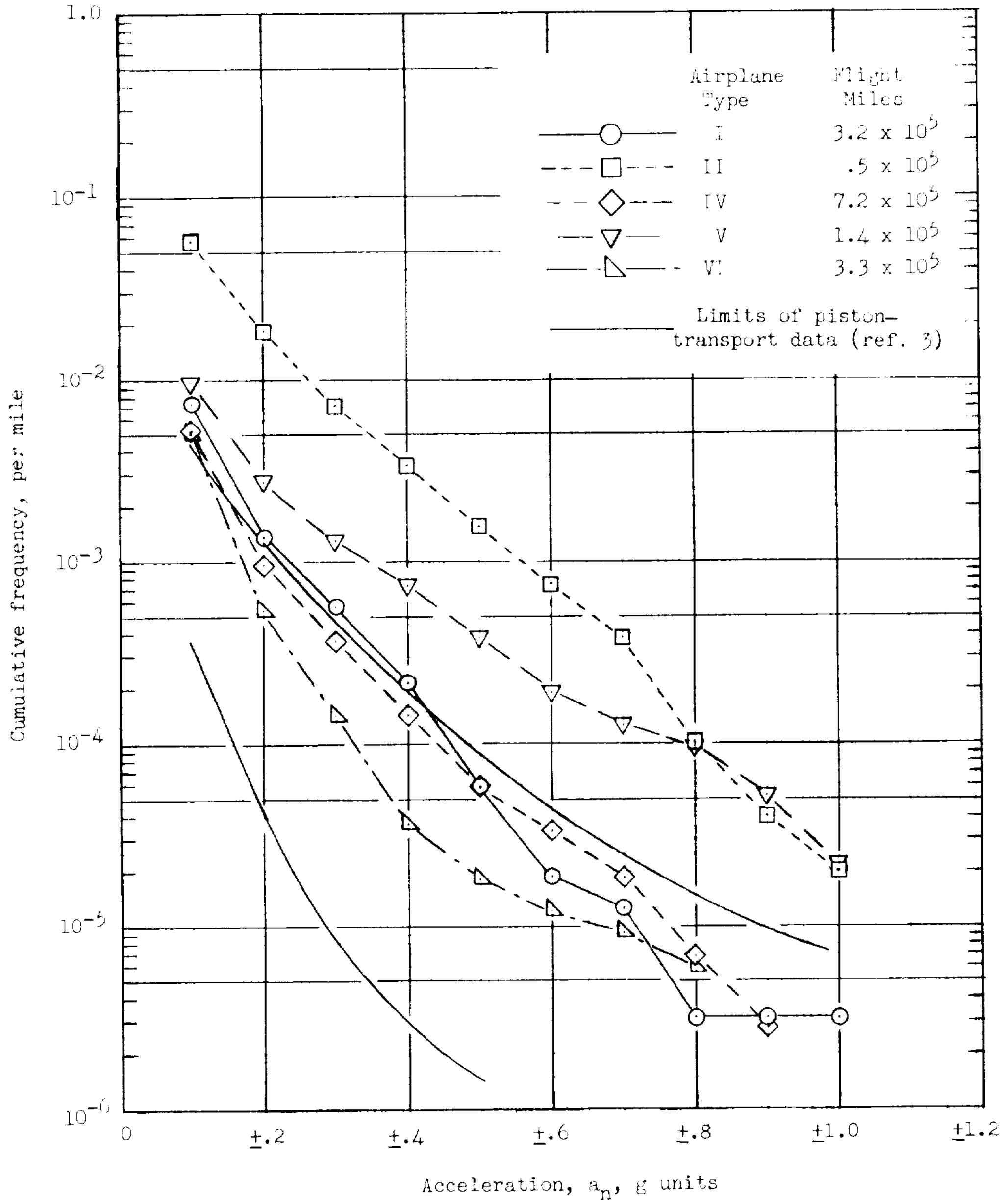


Figure 3.- Comparison of frequency of occurrence per mile of flight of check-flight maneuver accelerations for several types of airplanes.

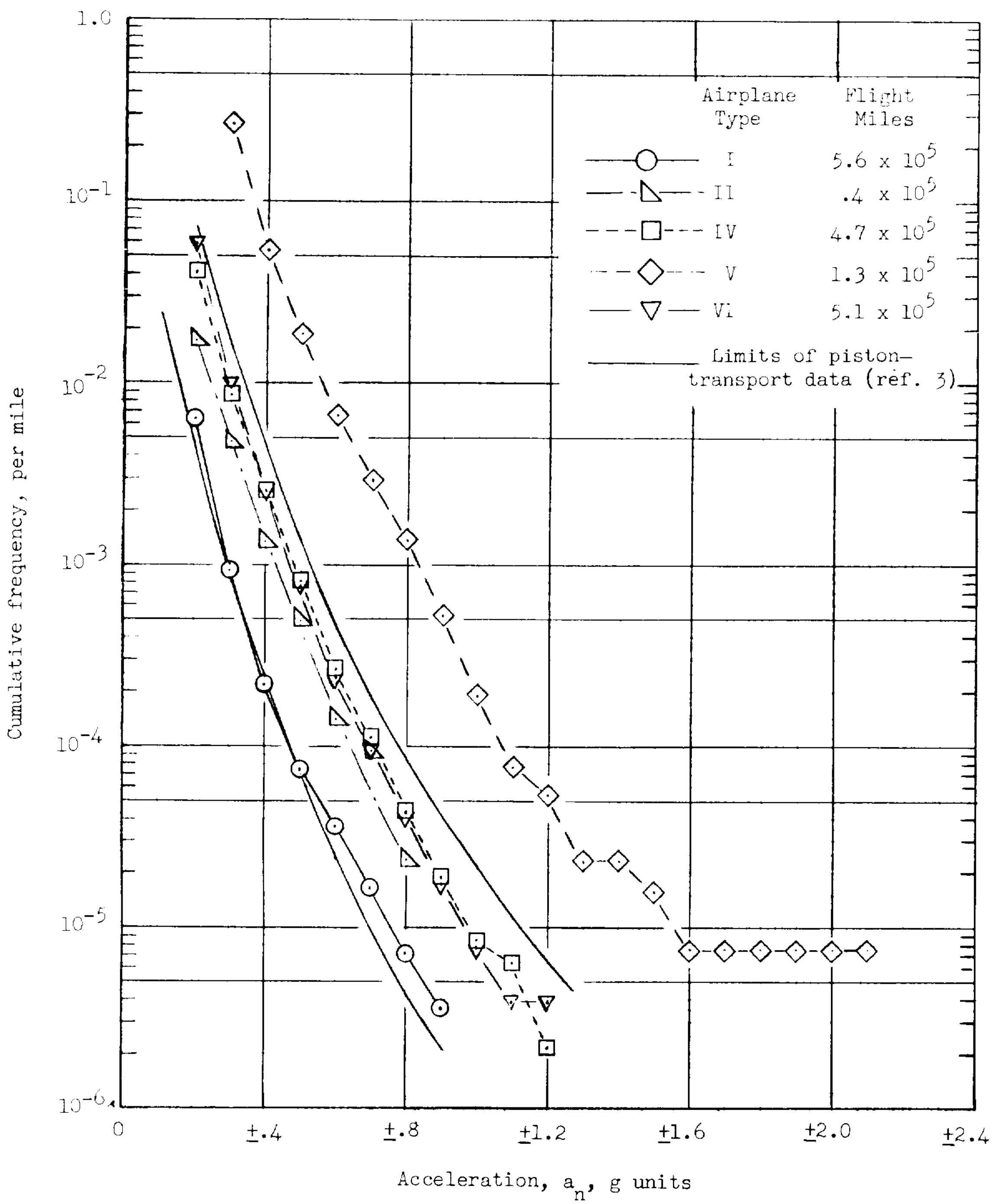


Figure 4.- Cumulative frequency of occurrence per mile of flight of operational gust accelerations for several types of airplanes.

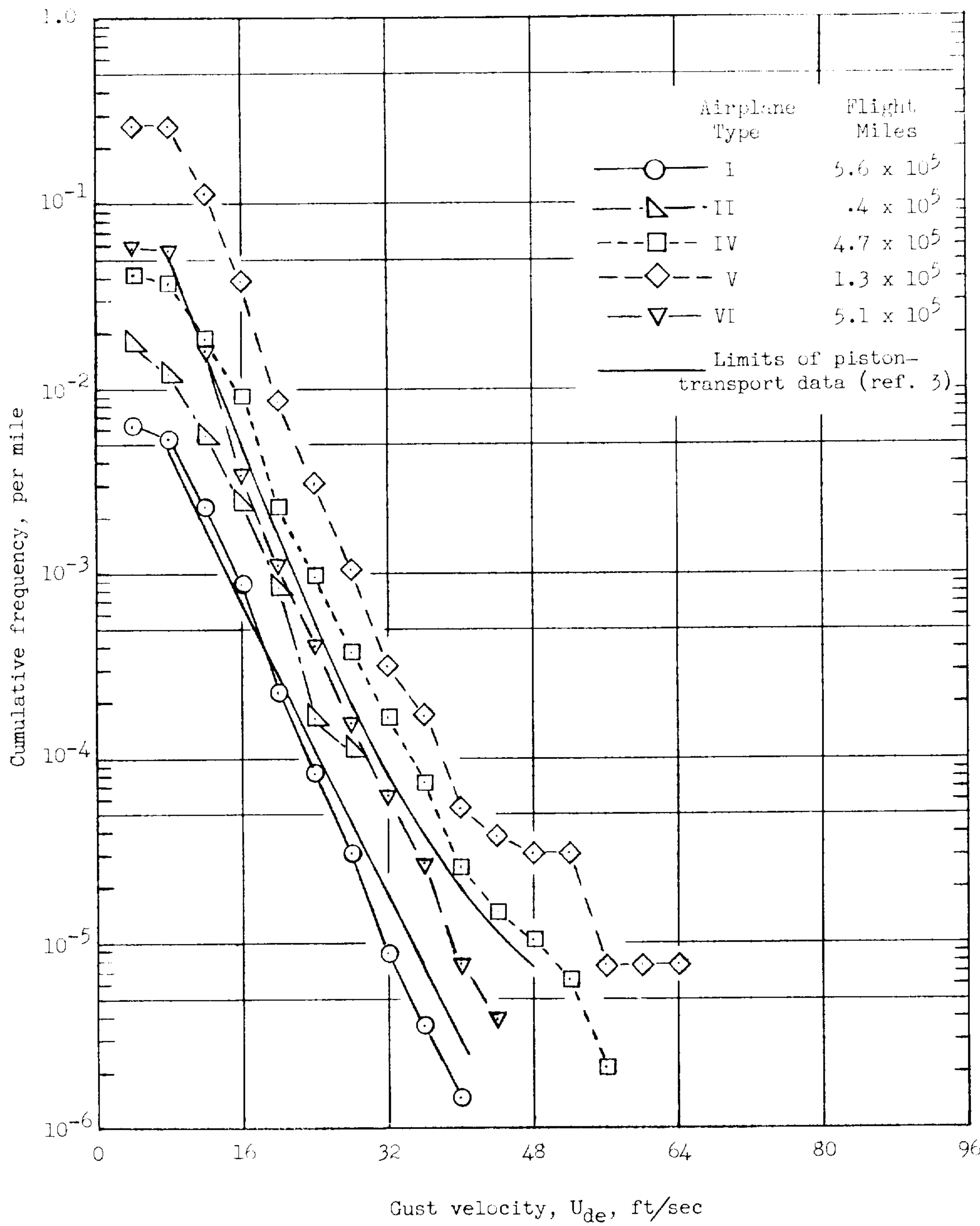


Figure 5.- Cumulative frequency of occurrence per mile of flight of derived gust velocities for several types of airplanes.

VII. MISCELLANEOUS EVENTS NOTED IN THE OPERATIONS OF TURBINE-POWERED COMMERCIAL TRANSPORTS

By Joseph J. Kolnick

SUMMARY

In the current VGH program being conducted on turboprop and turbojet commercial transports, a number of flight events that were unusual in regard to normal operations have been noted on passenger-carrying flights during climb, cruise, or descent. Such events were observed much less frequently in the past VGH programs conducted on piston-engine commercial transports. Some of these unusual operational events are described herein.

INTRODUCTION

Since the initiation of the VGH program on turbine-powered transports, various operational events that appear to be out of the ordinary in regard to transport operations have been noted on VGH records. Some concern has been raised regarding these events inasmuch as similar experiences were noted much less frequently in the VGH programs previously conducted on piston-engine aircraft. The purpose of this paper is to describe briefly a few of the unusual events as evidenced by the indicated airspeed, altitude, and normal acceleration.

EXAMPLES OF MISCELLANEOUS EVENTS

Some examples of miscellaneous or unusual operational events observed in the VGH records of commercial operations of turboprop and turbojet aircraft are presented in figures 1 to 7. All of these events occurred on passenger-carrying flights either in climb, cruise, or descent. Except for a few cases, no information is available concerning the occurrence of these events.

In regard to the frequency of occurrence of unusual events of the types presented in this paper, at least 40 such events were noted in about 10,000 flight hours. If divergent oscillations are also considered, at least 59 other occurrences were noted during the 10,000 flying hours where accelerations from $\pm 0.4g$ to about $\pm 0.9g$ were experienced.

In figure 1(a) an abrupt maneuver during climb is shown. The aircraft experienced an increment of 0.5g in acceleration as it climbed from a pressure altitude of 4,800 feet to 6,800 feet. At this time a push-over of -0.6g increment initiated a 15° descent to approximately 5,200 feet. Again, a positive incremental acceleration of 0.6g established the aircraft in a climb. This flight situation may have resulted from a collision-avoidance maneuver, although no information is available concerning this incident.

Another abrupt maneuver during climb is shown in figure 1(b). After an apparent attempt to level off following a climb to a pressure altitude of 2,700 feet, the airspeed began a rather rapid increase from about 175 knots to 285 knots in about one-half minute. An analysis of the data indicates that during part of this time the airplane had been in a turn. The aircraft was then pulled up into a climb of about 7,000 feet per minute or 15°. During this portion of the climb the airspeed dropped to 218 knots and the aircraft leveled off at an altitude of about 6,000 feet for about a minute. Following this event the aircraft continued on with a normal climb.

In figure 2 a large positive acceleration is indicated shortly after take-off, possibly as a result of a collision-avoidance maneuver. The peak value of acceleration was 2.7g or a positive increment of 1.7g. No information was available concerning this particular unusual occurrence.

In figure 3 a large loss in altitude soon after take-off is shown. Following take-off, the airplane climbed normally to a pressure altitude of 1,500 feet. At this point, the acceleration trace showed a positive increase as the aircraft entered a turn. During the turn, the altitude dropped back to about 600 feet above the ground as the airspeed continued to increase. From integrations of the acceleration trace, it appears that the aircraft turned approximately 180° with an angle of bank in excess of 45°. After this event the airplane was put into a steep climb and subsequently continued a normal climbout to cruise altitude.

Figure 4 shows an extremely low airspeed during cruise flight. Information obtained from the operator indicated that the pilot of the airplane reported experiencing moderate turbulence during the flight. The record shows the aircraft slowing to 100 knots as it descended from a pressure altitude of 29,000 feet to 23,000 feet. Possibly, this occurrence was an overshoot on a slowdown maneuver. The stall speed was estimated to be 98 knots for the particular flight condition and weight.

Figure 5 shows an aircraft entering the buffet boundary during cruise flight. On the basis of information available from the operator this airplane was at too high an altitude for its weight. A study of the airspeed trace indicated a slow gain of indicated airspeed until a Mach number of 0.85 was reached, at which time positive acceleration of 1.7g was experienced. In response to this acceleration the aircraft climbed 1,300 feet and the indicated airspeed decreased by about 45 knots as a result of the climb and perhaps some reduction in power. A number of instances similar to that shown in the figure have been recorded.

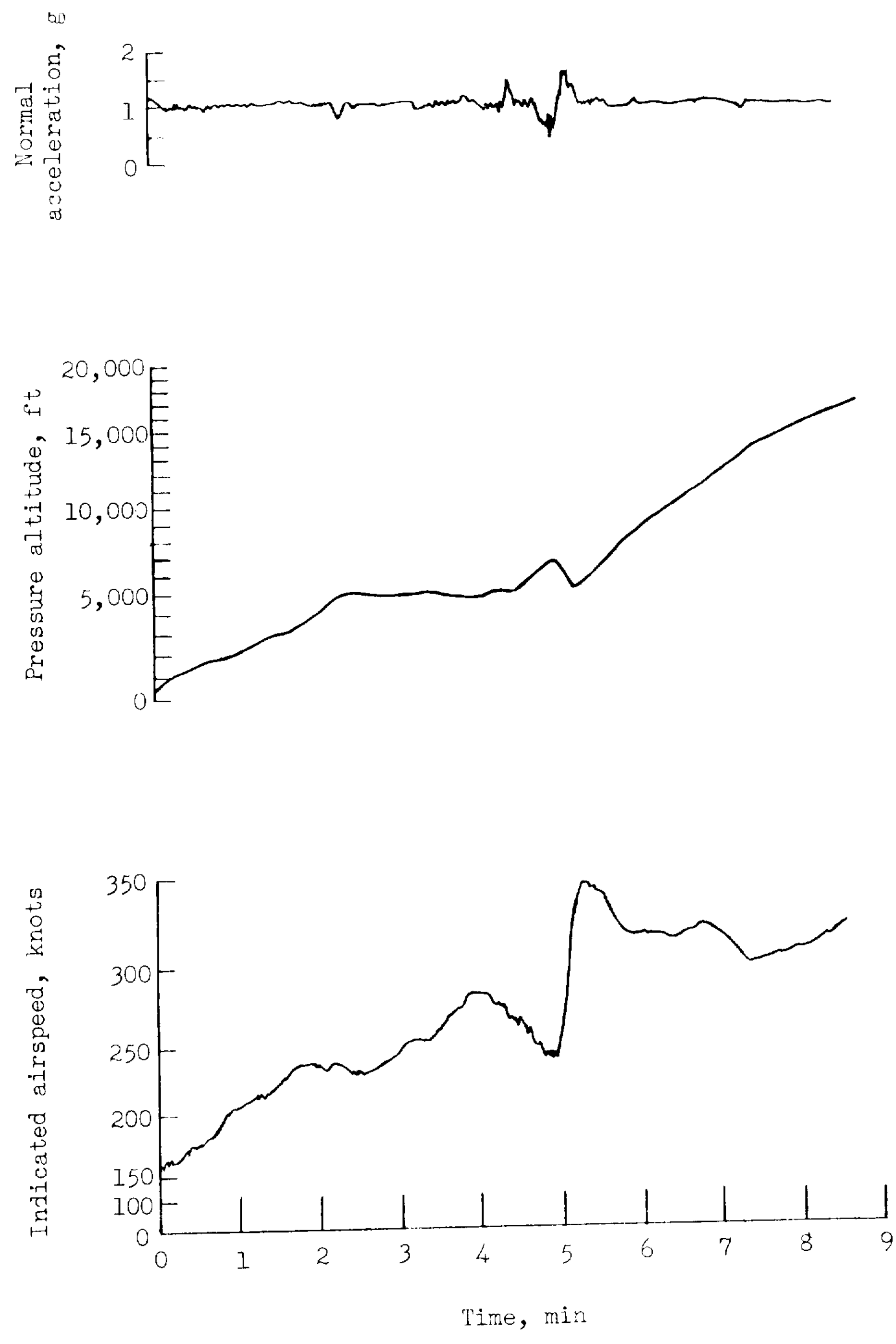
Figure 6 illustrates a flight in which normal accelerations up to 4.4g were experienced. On the basis of information obtained from the operator, the aircraft descended to a pressure altitude of 15,000 feet where it was to hold awaiting clearance to land. In making a turn to avoid one thunderstorm in the area the aircraft ran unexpectedly into another. The aircraft dropped on one wing and went into a spiral dive from which it recovered at a pressure altitude of 6,400 feet. In the dive the aircraft descended at a rate of about 20,000 feet per minute, and the indicated airspeed increased from about 225 knots to 405 knots. In the subsequent pull-out the normal acceleration at the center of gravity reached a peak value of 4.4g. Calculations indicated that, for the particular aircraft weight, the load factor of 4.4g was slightly under yield. Several inspections of the aircraft indicated no damage.

In figure 7 a landing approach is shown in which oscillation accelerations of ±0.4g (from 1.0g level) were experienced. During the approach the aircraft came down to a height of about 180 feet above the ground and then executed a go-around. In the second approach the oscillatory accelerations were still present but were of a smaller magnitude. Oscillatory accelerations during landing are unusual and it is suspected that the pilot may have aborted on the first approach because of them.

Oscillatory motions described in paper V by Milton D. McLaughlin may also be classified as unusual events inasmuch as they generally were not evident on piston-engine transports. In some of the divergent or convergent types of oscillations, normal accelerations as high as ±0.9g (from 1.0g level) were experienced.

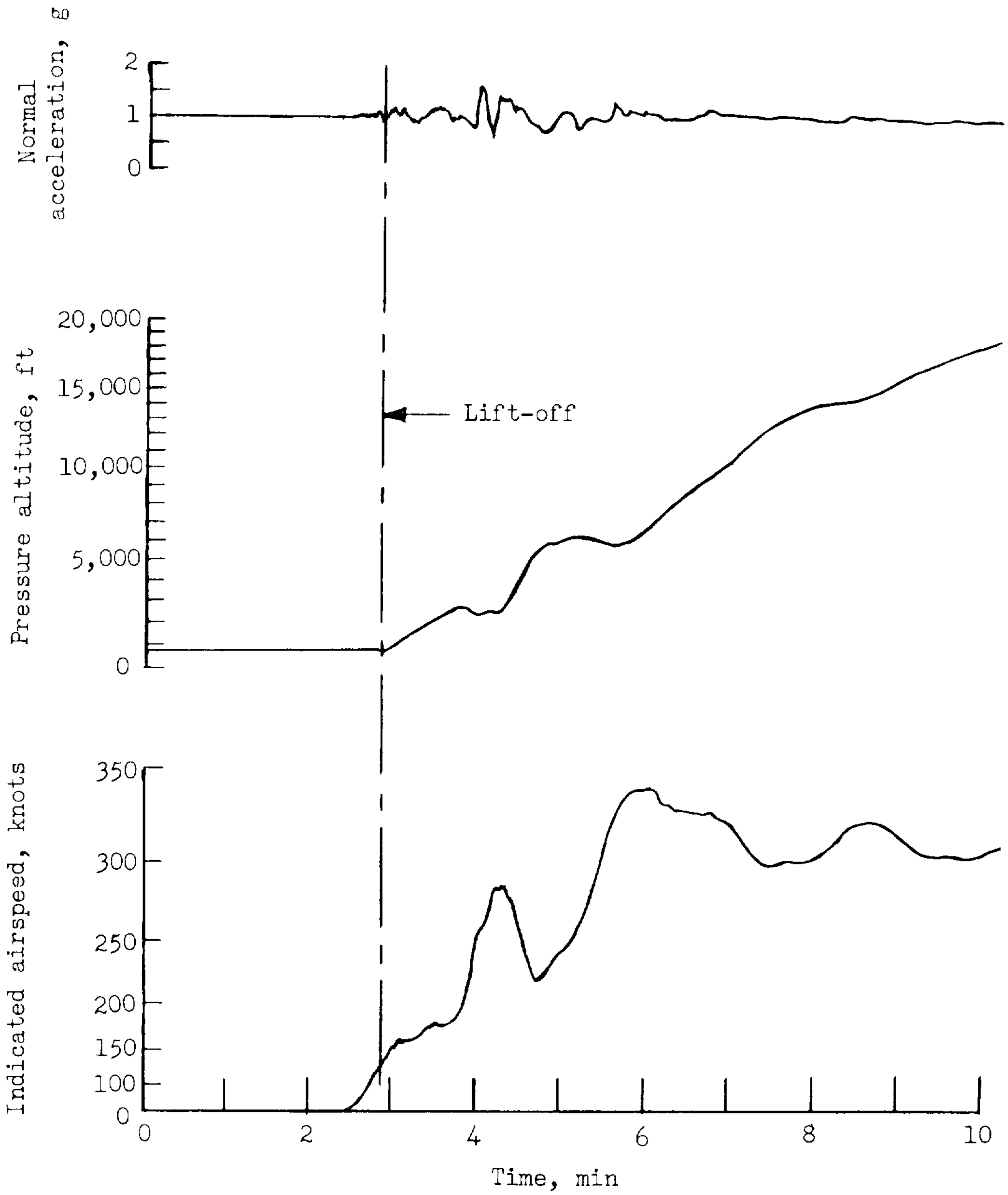
CONCLUDING REMARKS

In the current VGH program being conducted on turbine-powered aircraft a number of events that are of an unusual character in regard to normal operations have been noted. Such events have been noted much less frequently in VGH programs conducted in the past on piston-engine transports. It appears that the occurrence of these events in operations of current turbine-powered transports reflects the greater complexity of these aircraft, their higher speeds, and the greater density of air traffic.



(a)

Figure 1.- Abrupt maneuvers during climb.



(b)

Figure 1.- Concluded.

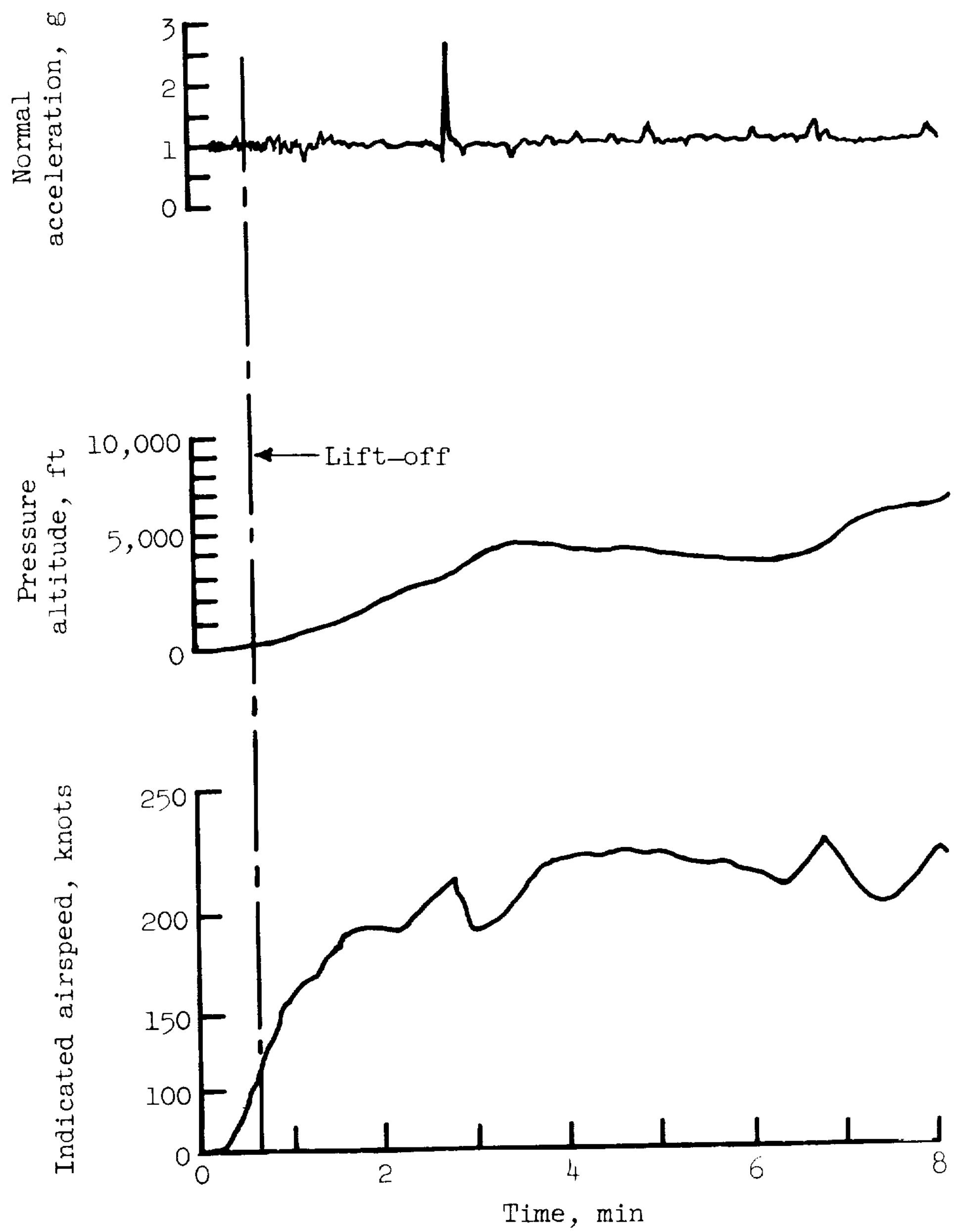


Figure 2.- Collision avoidance.

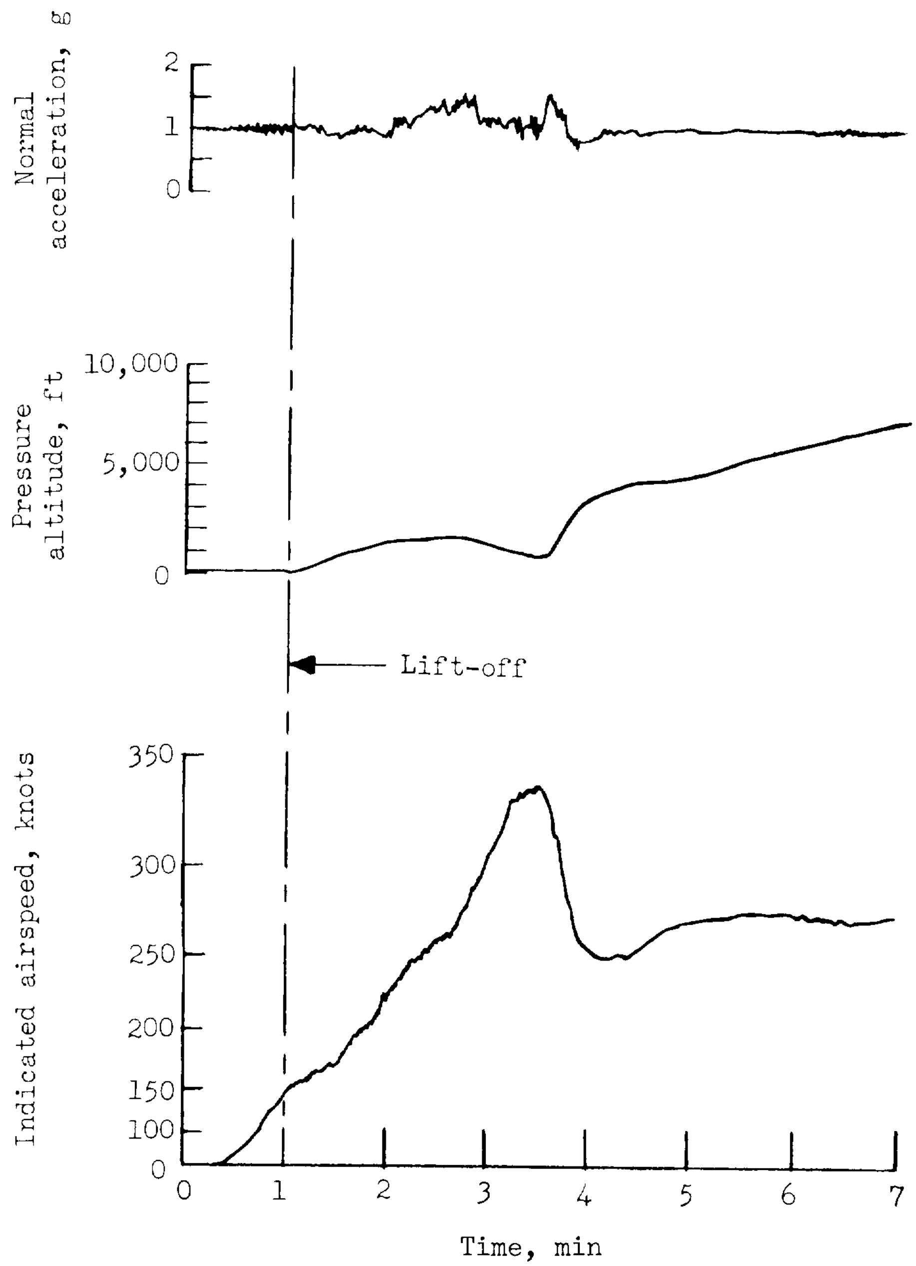


Figure 3.- Altitude loss following take-off.

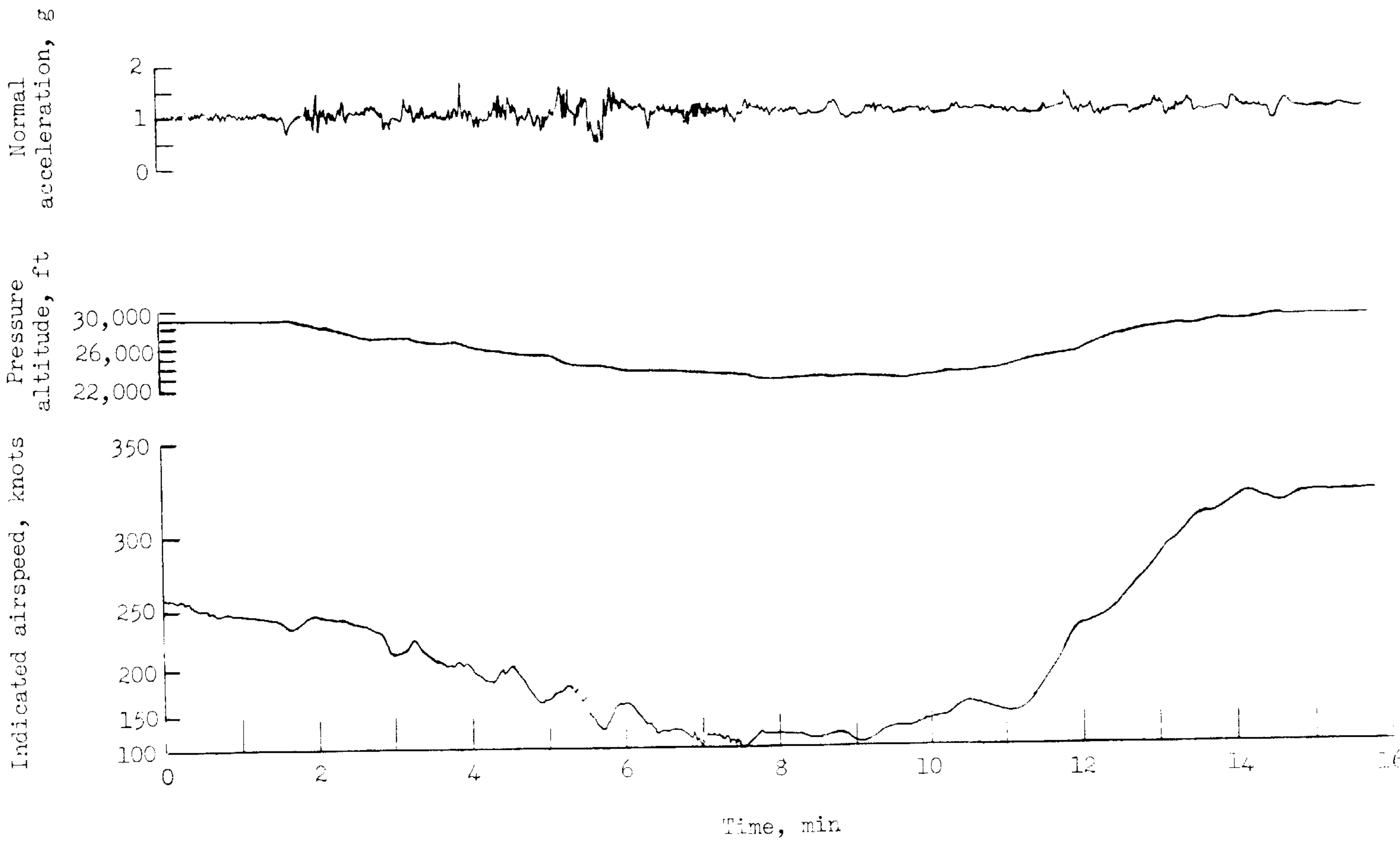


Figure 4.- Low airspeed during cruise.

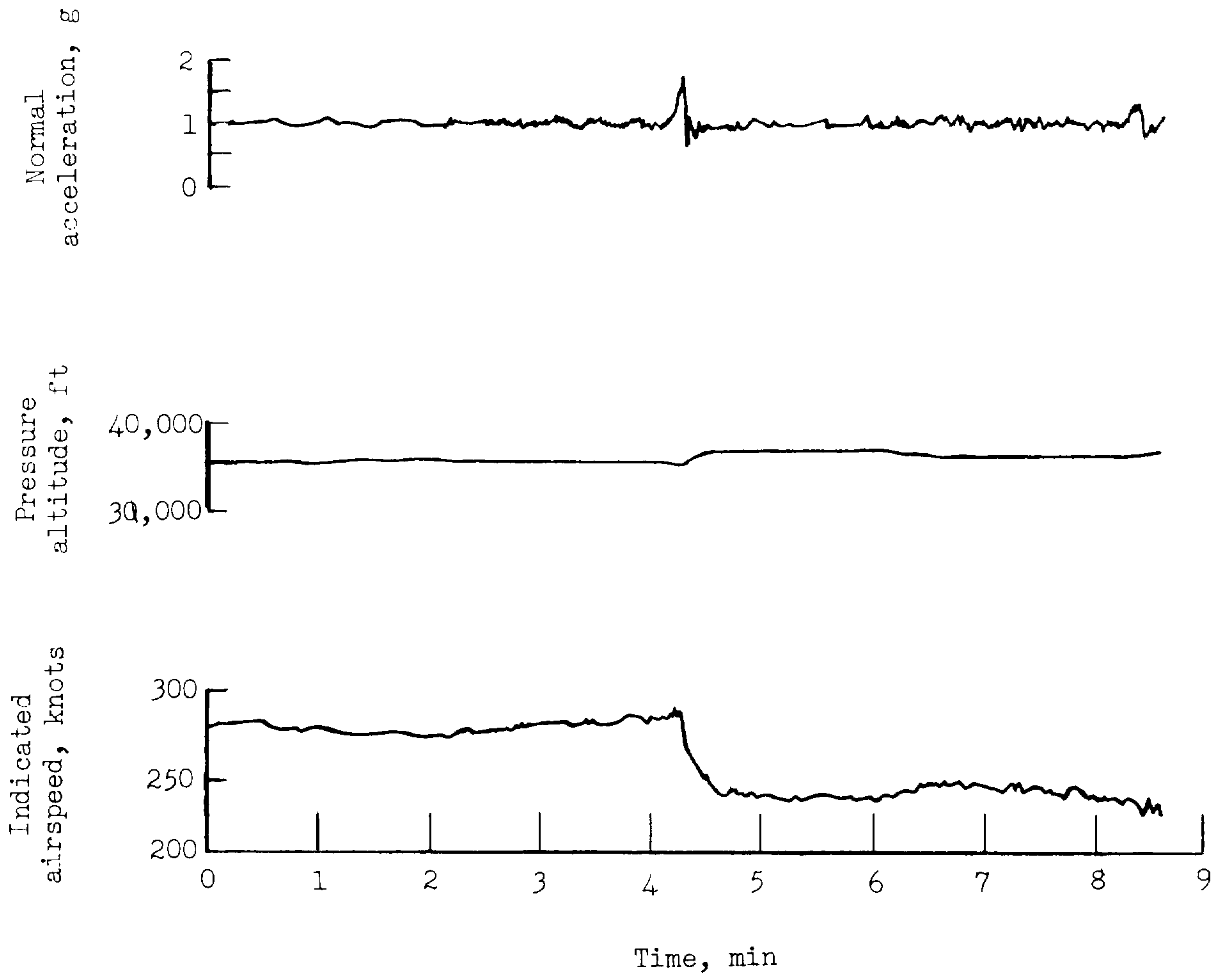


Figure 5.- High-speed buffet.

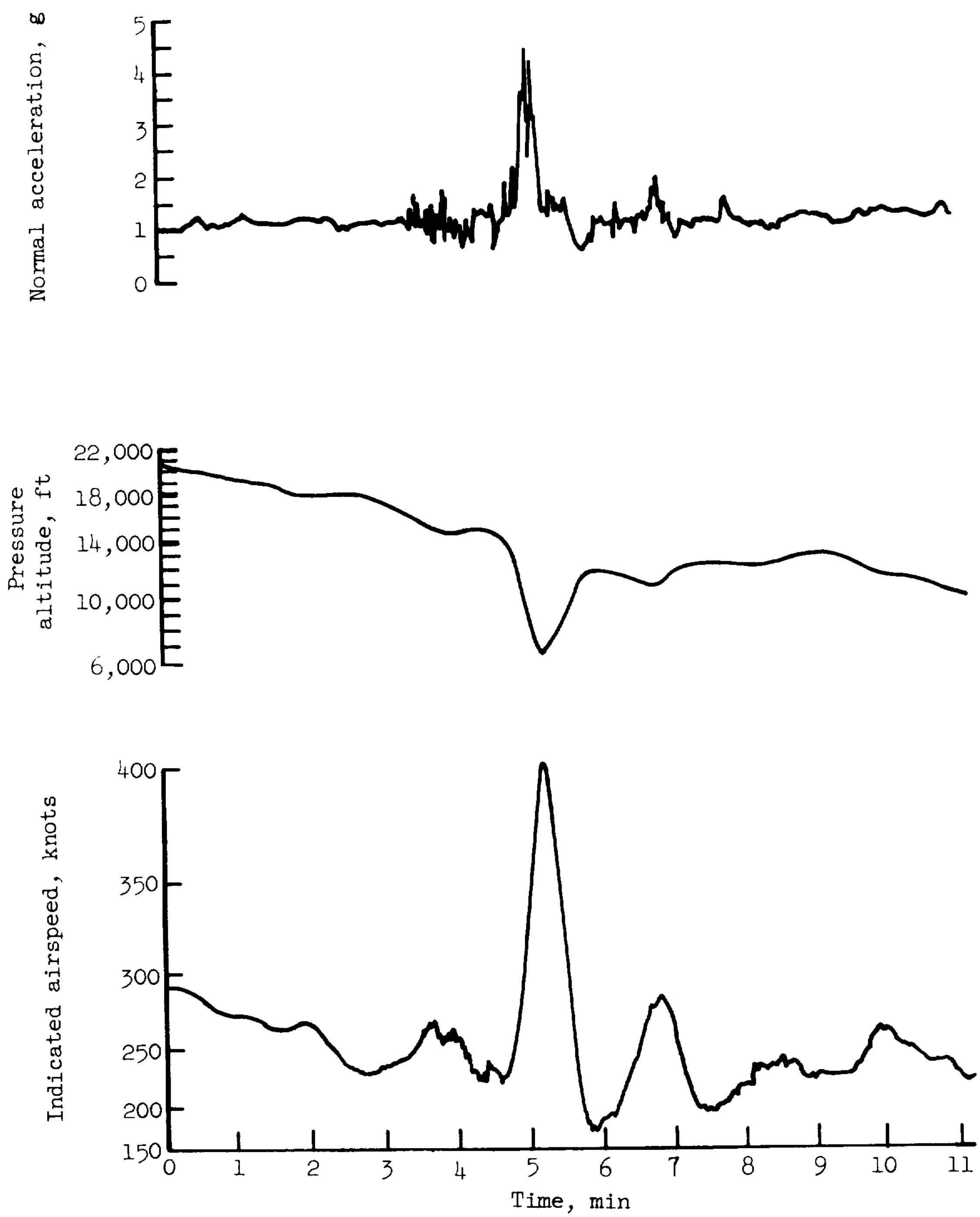


Figure 6.- Extreme maneuver acceleration experienced during holding in terminal area.

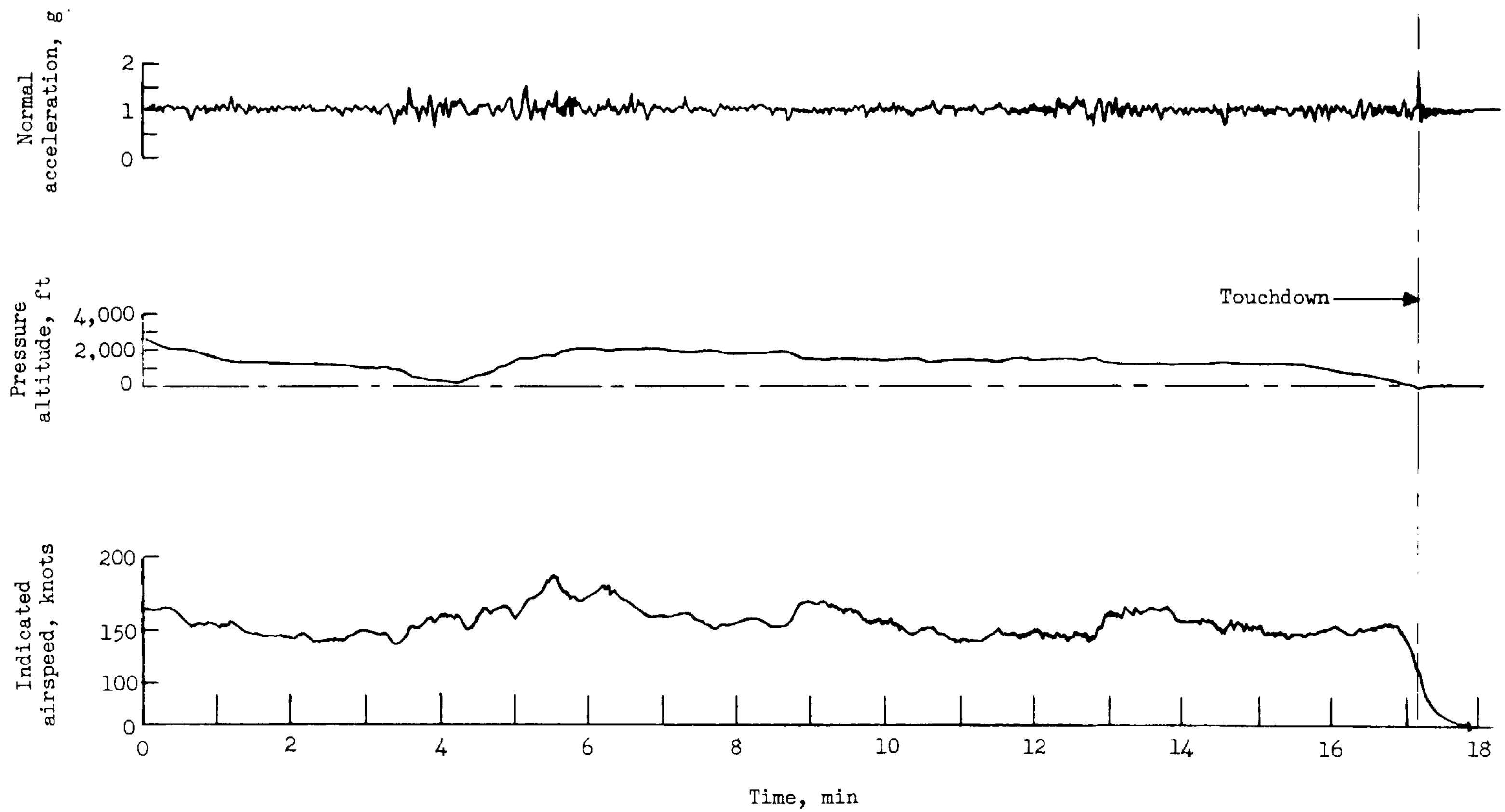


Figure 7.- Oscillations during landing approach.

RÉSUMÉ

In this series of papers some operational experiences of turbine-powered transports (turbojet and turboprop) are described. These experiences include the areas of landing-contact conditions, operating speed practices, aircraft oscillations, gust and maneuver accelerations, and miscellaneous events. The results are based on observations from VGH recorders and in the case of landing-contact conditions are supplemented by ground camera measurements.

Landing-Contact Conditions

In regard to landing-contact conditions appreciable differences in vertical velocity and acceleration at landing impact were experienced by some of the operators. The differences in vertical velocities between some operators were found to be as large as the differences between turbojet and piston-engine aircraft. While turbojet transports on the whole experienced vertical velocities about 25 percent higher than those experienced by piston-engine transports, one operator of turbojet transports experienced vertical velocities only slightly higher than those for the piston-engine transports, whereas another experienced vertical velocities significantly higher.

Correlation of vertical velocities for all classes of commercial transports (piston, turboprop, turbojet) has shown that vertical velocity at impact varied in a fairly consistent manner with aircraft weight, wing loading, distance of pilot forward of the landing gear, mean touchdown speed, and the effectiveness of the elevator in controlling the flight path. It is suspected that a principal factor in the higher vertical velocities for the turbojet transports is the relatively low effectiveness of the elevator in changing the flight path (1/3 to 1/7 of the elevator effectiveness of turboprop and piston-engine aircraft).

Analysis of VGH data has indicated no appreciable differences in the statistics for the landing-impact accelerations and the touchdown airspeeds for day and night operations. (In this analysis the data were not sorted according to weather conditions.)

Operating Speeds

In the original evaluation of VGH data on turbine-powered transports for the period prior to January 1960, it was found that the maximum speed attained by the transports frequently exceeded the placard normal-operating limit speed and, to a lesser extent, the placard never-exceed speed. For the recent evaluation covering a period from July 1960 to February 1961, the amount of overspeeding does not appear to have decrease

Aircraft Oscillation

Two types of oscillations were generally observed in the VGH records taken from turbine-powered aircraft. These oscillations were noted both with and without autopilot. One was a continuous type which was evident primarily as an oscillation in normal acceleration at the center of gravity and had low amplitudes (±0.05g to ±0.2g from 1.0g level) and periods generally 6 to 20 seconds. The other was a divergent or convergent type in which oscillations in acceleration reached values as high as 0.9g and -0.8g from the 1.0g level. The continuous type persisted from a few minutes to several hours, whereas the duration of the divergent or convergent type was usually of the order of 1 minute. The percent of flight time that the oscillations occurred ranged from as low as 0.2 percent for one type of aircraft to as high as 13.5 percent for another type (each type having from one to seven aircraft). The altitude and speed deviations corresponding to the continuous type of oscillation were rather small. For the divergent or convergent type, however, the overall variations in altitude were as much as 970 feet and in indicated Mach number and airspeed as much as 0.08 and 30 knots.

Gust and Maneuver Accelerations

Analysis of VGH records collected on the turbine-powered aircraft has provided information on the maneuvers experienced during routine operational and check flights, on gust accelerations experienced, and on gust velocities encountered. From the overall viewpoint, the results indicate that the turbine transports are maneuvered somewhat more frequently than were four-engine piston transports. In general, the gust-acceleration and gust-velocity histories for turbine airplanes do not appear to be significantly different from histories recorded on piston-engine airplanes.

Miscellaneous Events

A number of events have been observed on VGH records which are unusual with respect to normal operations and which were not observed as often on piston-engine aircraft in past VGH programs. These events occurred in the terminal areas and in cruise and appear to reflect increased speeds, aircraft complexity, and traffic density.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 19, 1962.

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